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TECHNICAL REPORT ARBRL-TR-02435

AEROSOLIZATION CHARACTERISTICS OF HARD IMPACT TESTING OF DEPLETED URANIUM PENETRATORS

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October 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report documents the findings of studies to ascertain the amount of depleted uranium (DU) aerosolized by hard impact testing of DU penetrators and characterize the particle size distribution of the aerosol. This study was performed at the request of the US Nuclear Regulatory Commission. It provides data useful in evaluating the potential health hazards to personnel of hard impact testing of DU penetrators.

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I. INTRODUCTION

A. Background

U.S. Army Ballistic Research Laboratory (BRL), U.S. Army Armament Research and Development Command (ARRADCOM), Aberdeen Proving Ground (APG), Maryland has primary responsibility in Ballistic Research. The fields of research in BRL include, but are not limited to, investigation of propellants, projectile flight characteristics, terminal effects, fire and incendiary effects, and target vulnerability and vulnerability reduction.

In an effort to develop an enhanced armor penetrating projectile, BRL began studying the performance of depleted uranium (DU) penetrators. Until June, 1979, BRL conducted DU penetrator research at ranges at Aberdeen Proving Ground, Maryland and elsewhere in the continential United States. On 20 June 1979 the US Nuclear Regulatory Commission (NRC) issued a license amendment which stated that BRL could "not conduct destructive testing involving source material such that any airborne radioactivity would be released to unrestricted areas." This amendment, which resulted in a moratorium on all BRL destructive testing of DU penetrators was the result of NRC concern about DU aerosolization at the time of penetrator impact with an armor target and the potentially adverse affect of the aerosol on personnel. (The environment at outdoor ranges at APG precluded accurate determination of characteristics of the aerosol generated.)

In order to continue DU penetrator research, a large caliber target enclosure was constructed at Range 14, Spesutie Island, Aberdeen Proving Ground, Maryland. On 24 August 1979 the NRC authorized the destructive testing of ten DU penetrators at Range 14 to verify the integrity of the enclosure. On 18 July 1980 the NRC authorized the destructive testing of an additional twenty DU penetrators at Range 14 to obtain data to allow characterization of the aerosol generated by penetrator impact with armor target.

B. Objective

This study was performed to determine the percentage of DU penetrators aerosolized by penetrator impact with hard targets and to ascertain particle size characteristics and the percentage of the DU aerosol which is respirable.

C. Facility Description

BRL's Range 14 (R-14) is located in the southwestern portion of Spesutie Island, Aberdeen Proving Ground, Maryland. This range is used for research and developmental testing of large caliber (up to 120mm) kinetic energy (KE) penetrators, generally of the armor piercing, fin-stablized, discarding sabot (APFSDS) type. The facility is used to fire penetrators at muzzle velocities up to about 2290 meters per second (7500 feet per second) over distances of up to 305 meters (1000 feet) into various target materials and configurations. Penetrators with masses of up to five kilograms (11 pounds) can be fired at this range.

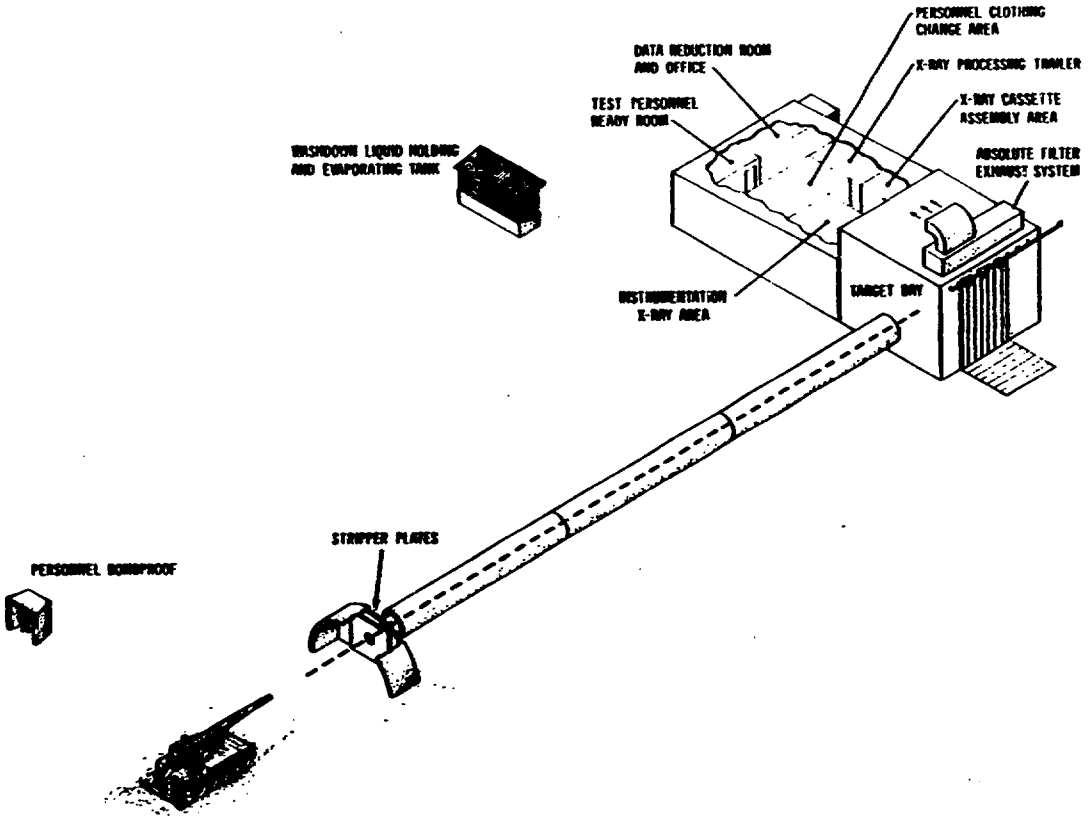


FIGURE 1. Range 14, Spesutie Island

The penetrator firing portion of the R-14 test site consists of a gun pad (projectile launch position), stripper plate, projectile flight tube (PFT), and target bay. (See Figure 1). The gun pad is currently located 61 meters (200 feet) uprange from the target and is not enclosed. The stripper plate assembly (See Figure 2) is a 3.7 meters (12 feet) radius, 14 centimeters (5 1/2 inch) thick, 2.4 meters (8 feet) deep half-cylinder, which is designed to prevent sabot parts from travelling laterally after impaction. The PFT is located about 15 meters (50 feet) downrange from the muzzle and consists of 46 meters (150 feet) of 2.4 meters (8 feet) diameter, 2.5 centimeters (one inch) thick steel pipe. The target bay is an all steel-armor enclosure 9.1 meters (30 feet) square by 7.3 (24 feet) high.

When a projectile is fired it travels downrange through a hole in the stripper plates, into and through the PFT and into the target bay where the target is impacted. Overpressure in the target bay due to penetrator impact with the target causes aerosolized depleted uranium to be released into the PFT, which is essentially an extension of the target bay. The presence of seals on the personnel and equipment doors limits aerosolized DU to these areas.

Cleaning of target bay air is accomplished by filtration. Filtration of the 170 cubic meters (6000 feet) per minute of air flow is provided by a bank of six moderate efficiency prefilters (30 percent efficiency for 0.5 micron particles) followed by banks of six each high efficiency (95 percent efficiency for 0.5 micron particles) prefilters and high efficiency particulate air filters (99.97 percent efficiency for 0.3 micron particles). Air flow is through the PFT into the target bay with exhaust through a fragment shield, ducted hole in the roof, and the range ventilation/ filtration system.

D. Summary of Testing Conducted

Sampling was conducted during a research firing program which consisted of testing, against armor targets, 75mm rounds which had DU penetrators. The 2.27 kilogram penetrators were fired at velocities of 1463 meters per second (4800 feet per second) and 1646 meters per second (5400 feet per second) into single and triple plate target configurations. Round specific velocity-target data is listed in Table 1. This program was a regulatory scheduled part of R-14's research and development firing schedule and thus is indicative of routine testing.

Sampling accomplished included the collection of total particulate and particle sizing samples of the DU aerosol which was airborne during the applicable sampling period. Additionally, all material which was on the floor of the target bay was collected after each round (DU fallout and pieces of DU, steel, plywood, etc). As a cross-check on the total aerosolization data, prefiring and post firing weights of one set of range ventilation system filters were also obtained and samples of these filters were analyzed to allow estimation of the percentage of penetrator mass which was collected by the filters.

TABLE 1. BALLISTIC PARAMETERS FOR TESTING PERFORMED

ROUND	VELOCITY (meters/second)	TARGET
1	1463	Triple-Plate
2	1463	Triple-Plate
3	1463	Triple-Plate
4	1463	Single-Plate
5	1463	Single-Plate
6	1463	Single-Plate
7	1463	Triple-Plate
8	1646	Single-Plate
9	1646	Single-Plate

NOTES: (1) *All rounds were 75mm and had depleted uranium penetrators weighing 2.27Kg each.*

(2) *Round 6 did not penetrate the target completely.*

Nine firings were sampled with a total of 54 total particulate and 12 particle sizing samples being collected and analyzed. Many data points were lost due to impaction of sampling equipment and electrical lines by fragments. Additionally, no particle size data was obtained for Round One and, although analyzed and results included in this report, the accuracy of Round Two particle size data is questionable. (These difficulties resulted from the amount of particulate collected exceeding the design capacity of impactors, thus, resulting in re-entrainment

II. DETAILED EXPERIMENTAL PROCEDURES

A. Test Preparation

Prior to testing, all sampling and analysis equipment was calibrated to applicable specifications using NBS-traceable standards and appropriate procedures. Additionally, the Range 14 target bay and projectile flight tube were decontaminated prior to testing to remove excessive residual depleted uranium from previous tests.

B. Estimation of the Percentage of Penetrator Aerosolized

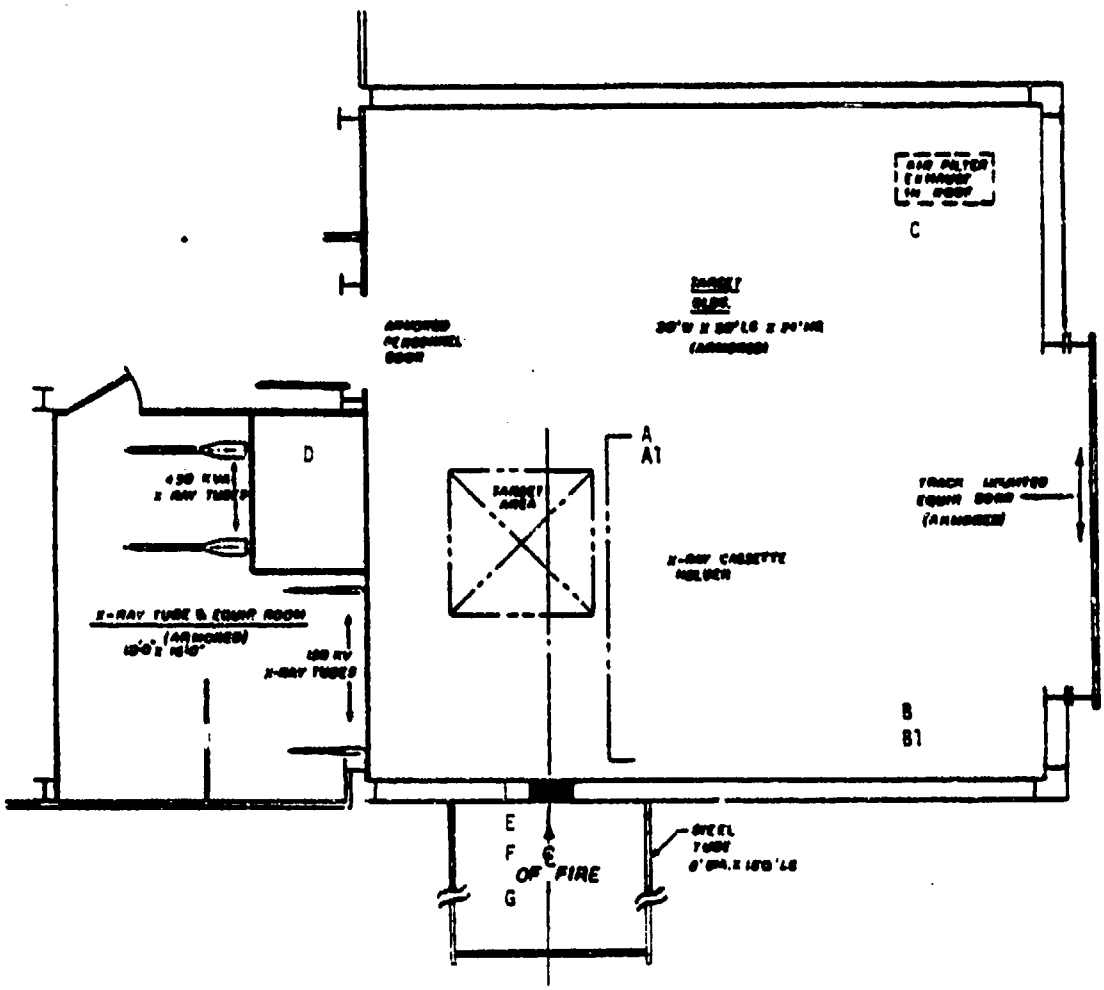
1. Synopsis

An estimation of the percentage of penetrator mass which was accomplished by placing total particulate samplers in the target bay and projectile flight tube. The results of these samples reflected the concentration at the applicable sampling location. If assumptions are made regarding the nature of the dispersion of the aerosolized DU in the target bay and PFT, these concentrations can be readily converted to total amount of depleted uranium which was airborne during the sampling period (i.e., concentration per unit volume times volume equals total amount airborne). Dispersion assumptions made were, 1) That the uranium aerosol in the target bay was equally dispersed throughout the room and, 2) that the airborne uranium was dispersed such that the average concentration in each of three segments of the PFT equalled the concentration at the sampling point in the applicable segment.

2. Sample Collection

Four total particulate samplers were initially installed at preselected locations in the target bay. Three total particulate samplers were placed in the PFT 1.5 meters (5 feet), 7.6 meters (25 feet) and 15 meters (50 feet) uprange from the target bay. (See Figure 2 for sampling locations.) All samplers were wired for remote operation.

Total particulate samplers used in the target bay included three General Metal Works Model GMWN-2600 Accuvol Samplers and one Staplex Model TF1A Air Sampler. Each of these samplers used Whatman Model 41 cellulose-based filters. Cellulose filters were required so as to avoid filter damage



NOTE: (1) A thru G represent locations of total particulate samplers while A1 and B1 were locations of particle size impactors.

(2) Total particulate samplers E, F, and G were located in the projectile flight tube 1.5, 7.6, and 15 meters (5, 25 and 50 feet) uprange from the target bay.

FIGURE 2. SAMPLING LOCATIONS

by the shock wave which results from penetrator impact with the target. The Accuvol Samplers utilized constant flow controllers and operated at 140 leters (5 cubic feet) per minute. The Staplex sampler, which was used only for Round One testing due to fragment damage during Round Two, was operated at a flow rate of 700 liters (25 cubic feet) per minute. The average flow rate of the Staplex sampler was utilized to determine total volume sampled.

All samplers utilized elapsed time meters as a cross-check on manual sample timing.

Total particulate samplers used in the PFT consisted of three Staplex Model TFIA air samplers. These samplers used Gelman Type A glass filters and were placed 1.5 meters (5 feet), 7.6 meters (25 feet), and 15 meters (50 feet) uprange from the target bay. The average flow rates for these samplers were 0.79, 0.93 and 0.96 cubic meters (28, 33, and 34 cubic feet) per minute.

All sampling was initiated two minutes after firing. The sampling durations was four minutes for Rounds One, two minutes for Round Two and one minute for Rounds Three through Nine. Reduction of the sampling duration was accomplished so as to maintain the same sample period for total particulate and impaction samplers. (The sampling duration of impaction samplers was reduced to avoid exceeding their design capacity for collection.) All sampling was accomplished without the ventilation system operating except sampling for Round Three, when it inadvertently was left on. (Normal firing procedures require that the ventilation system be on at the time of firing to minimize release of airborne uranium into the PFT.)

Estimation of the total amount of uranium aerosolized required assumptions to be made regarding the nature of the dispersion of the airborne material. Calculations assume that the mean concentration of airborne DU was equal to the mean of the sample points in the target bay. All samples were obtained 1.2 to 1.8 meters (4 to 6 feet) above the floor and are therefore not representative of the actual dispersion in the vertical direction. They should, however, approximate worst case due to the height of the sample relative to the target stand.

Estimation of the total aerosol formed also required an assumption about the nature of the dispersion of airborne uranium in the PFT.

Calculations assume that the average concentration in each of segments of the PFT equalled the concentration at the sampling point in the segment. Samples were obtained 1.5 meters (5 feet), 7.6 meters (25 feet), and 15 meters (50 feet) uprange from the target bay. The concentrations at these points were applied to the segments 0 to 4.6 meters (0 to 15 feet), 4.6 to 11.6 meters (15 to 38 feet), and 11.6 to 18.9 meters (38 to 62 feet), respectively.

3. Sample Analysis

A two-inch diameter portion was cut from each sample. This portion was counted for gross alpha and beta using a Canberra Model 2201, Low Background Alpha/Beta Proportion Counting System. Each sample was counted for 200 minutes after awaiting a minimum of 72 hours for the decay of radon and thoron and their daughters. Counting efficiency was determined using NBS-traceable Th-232 and Sr-90 sources for alpha and beta, respectively. The background count rate was obtained also using 200 minute counts.

Results were converted to microcuries per milliliter with counting error calculated at the 95 percent confidence level. All results assumed 30 percent self-absorption of alpha radiation. (This value was derived from filter manufacturer's specifications for cellulose filters. The actual self-absorption is less for glass fiber media[1].) A collection efficiency of 95 percent was used for cellulose filters and 100 percent for glass fiber filters[1]. This collection efficiency for cellulose filters should be the worst case. Results were obtained for both alpha and beta with beta results used as an additional cross-check. This was accomplished by comparing the actual alpha to beta ratio of depleted uranium to individual sample results.

Results were derived from individual sample data using computational procedures in Section III. Individual sample results and empirical data derived from these results are listed in Section V.

C. Particle Sizing Determination[2]

1. Synopsis

Particle size determination was accomplished by placing Anderson Model 2000 four-stage particle size impactors in the target bay. These high volume impactors measure the aerodynamic size distribution of particulates so that all particles collected are sized aerodynamically equivalent to unit density (One gram per cubic centimeter) spherical particles. Analysis of the amount of uranium on each stage and on the backup filter allowed calculation of the percentage of uranium in each size range. Graphing of the cumulative percent less than the stated size for the applicable stage versus particle size in microns for that stage allowed determination of the mass mean aerodynamic diameter (MMAD) and standard geometric deviation. (The MMAD is a statistical measurement of the diameter above or below which half the total mass of the distribution occurs. The standard geometric deviation is not a statistical unit as such but is, instead an index of dispersity with a value of one when all particles are the same size and increasing for broader sized particle spectra.)

1. GUIDE SAMPLING RADIOACTIVE MATERIALS IN NUCLEAR FACILITIES, (ANZI N 13.1-1969) American National Standards Institute, Inc., New York, NY, February, 1969.
2. OPERATING MANUAL FOR ANDERSON SAMPLERS, INC., HIGH VOLUME PARTICLE SIZING SAMPLERS, Anderson Samplers, Inc., Atlanta, GA, October, 1979

2. Sample Collection

Two Anderson Model 2000 Particle Size Impactors were emplaced in the target bay with one of these samplers located adjacent to the target stand and the other being placed in another part of the room. (See Figure 2). All impactor samples were obtained about 1.22 meters (4 feet) above floor level. These samplers are four-stage cascade impactors which operate at a constant flow rate of 0.57 cubic meters (20 cubic feet) per minute using a Model 700 Constant Flow Controller. This sampler classifies the particles collected according to the aerodynamic dimension into size ranges of greater than 7.0 microns, 3.3 to 7.0 microns, 2.0 to 3.3 microns, and 1.1 to 2.0 microns, with a glass fiber backup filter to collect particles less than 1.1 microns.

3. Sample Analysis

The collection filter from each impaction stage was quartered with the backup filter being halved. Two quarters from each impaction filter and one half of each backup filters were submitted to Radiation Management Corporation (RMC) for independent analysis of these samples. (See Appendix A for results of RMC Analysis). BRL health physics personnel analyzed the remaining portions.

The impactors utilize two configurations of specially designed, cut and perforated collection filter. Configuration I is used for stages one and three while Configuration II is used for stages two and four. Sampling for results in well-defined discrete piles of particulate with the number of such piles varying for the two configurations of collection filters.

BRL analysis of the impactor stage filters consisted of obtaining a two inch diameter portion from each of the two remaining quarters of the collection filter. These samples were obtained insuring that the same number of piles of particulate were on each sample (a variation in the number of piles of up to about one-third could occur from random sampling). Each of the two inch samples were counted using a Canberra Model 2201 Alpha-Beta Proportional Counting System. Results of the two samples were averaged, corrected for sample size and self-absorption and converted from radiological units to mass units. Alpha self-absorption of 30 percent was assumed in lieu of a more accurate value. A maximum of 75 millograms can be collected on each stage without exceeding impactor capacity. Due to the small amount of particulate collected and the low self-absorption for alpha for glass fiber filters, this value probably represents worst case. Beta results were used as a cross-check in the same manner as for total particulate samples.

Backup filters were analyzed in the same manner as total particulate samples. Two 2-inch diameter samples were analyzed from each such filter with the average of the results converted to mass units.

Results were derived from individual sample data using computational procedures in Section III. Individual sample results and empirical data derived from these results are listed in Section V.

Mass mean aerodynamic diameter and geometric standard deviation data were derived from graphs of Cumulative Percent Less Than Stated Size (the upper limit of each impaction stage) versus Particle Size in microns. The particle size geometric standard deviation (σ_g) is given by:

$$\sigma_g = \frac{84.13\% \text{ diameter}}{50\% \text{ diameter}} = \frac{50\% \text{ diameter}}{15.87\% \text{ diameter}}$$

D. Analysis of the Amount of Uranium Collected by Range Ventilation System Prefilters

These analyses were accomplished for comparison with the total amount of uranium aerosolized as derived from total particulate sampling data.

Each of the six prefilters in each of the two banks of prefilters was weighed prior to installation in the target bay nuclear air cleaning system. These filters consisted of banks of 30 percent efficiency and 95 percent efficiency (for 0.5 micron particles) prefilters and were installed prior to firing Round Seven.

After Rounds Seven and Eight were fired, these prefilters were removed from the ventilation system and reweighed. Two samples of about one gram each of the particulate were obtained randomly from each prefilter. These samples were analyzed for gross alpha and beta using the procedures previously outlined to determine the percentage of the particulate on the prefilters which was uranium. The amount of uranium on the filter was thus, derived as a percentage of the weight of particulate collected by the prefilters. Summing the uranium on each prefilter gave the total amount of uranium collected by the ventilation system prefilters.

The systematic error which resulted from use of these procedures is probably substantial (See Section IV for Error Analysis). It does provide, however, an approximation of the total amount of uranium aerosolized which is useful as a cross-check on total particulate data. Results of these analyses are listed in Section V while computational procedures are in Section III.

III. COMPUTATIONAL PROCEDURES

A. Estimation of Total Airborne Uranium

Gross Particulate alpha or beta air activity in microcuries per milliliter (with two standard deviations counting error)[3]:

---

3. Hirman Cember, Introduction to Health Physics, Pergamon Press, New York, NY, 1969

$$\mu Ci/ml = \frac{NCPM \pm 2\left(\frac{R_{s+b}}{t_{s+b}} + \frac{R_b}{t_b}\right)^{1/2}}{(E)\ (Y)\ (F_{sa})\ (F_r)\ (V)\ (2.22 \times 10^6 dpm/\mu Ci)}$$

where:

CPM = Counts per minute

NCPM = Net CPM

E = Counting efficiency

Y = Filter collection efficiency

F_{sa} = Self-absorption factor

F_r = Fractional percent of sample counted

V = Volume of air sampled in milliliters

R_{s+b} = Count rate of a given sample (with background)

R_b = Background count rate

t_{s+b} = Counting time of a given sample

t_b = Background counting time

AMOUNT OF AIRBORNE DEPLETED URANIUM IN THE TARGET BAY:

$$X_1^* = \frac{\Sigma X}{n}\left(\frac{g}{0.36\mu Ci}\right)V$$

where:

X_1^* = Amount of airborne DU in the Target Bay

X = Results of individual total particulate sample in microcuries per milliliter

n = Number of total particulate samples obtained for a particular round

V = Volume of the Target Bay in milliliters

$\frac{g}{0.36\mu Ci}$ = Conversion factor from radiological to mass units for DU

AMOUNT OF AIRBORNE DU IN THE PROJECTILE FLIGHT TUBE:

$$X_2^* = (X_1V_1 + X_2V_2 + X_3V_3)\ \frac{g}{0.36\mu Ci}$$

where:

X_2^* = Amount of airborne DU in the PFT, in grams

X_1 = Air concentration in PFT five feet uprange from target bay, in microcuries per milliliter

V_1 = Volume of the initial 15 feet of the PFT ($V = \pi r^2 l$) in milliliters

X_2 = Air concentration in the PFT 25 feet uprange from the target bay, in microcuries per milliliter

V_2 = Volume in milliliters of the PFT from 15 to 38 feet uprange from the target bay

X_3 = Air concentration in the PFT 50 feet uprange from the target bay, in microcuries per milliliter

V_3 = Volume in milliliters of the PFT from 38 to 62 feet uprange from the target bay

TOTAL AMOUNT OF DU AIRBORNE:

$$X^* = X_1^* + X_2^*$$

where:

X^* = Total amount of DU airborne

X_1^* = Amount of aerosolized DU in the target bay

X_2^* = Amount of aerosolized DU in the projectile flight tube

PERCENTAGE OF PENETRATOR AEROSOLIZED:

$$P_p = \frac{(X^*)(100)}{M_p}$$

where:

P_p = Percentage of penetrator aerosolized

X^* = Total amount of DU airborne, in grams

M_p = Mass of penetrator, in grams

SAMPLE CALCULATION (from Round One):

(1)

$$\mu Ci/ml = \frac{2203.12 \text{ cpm} \pm 2\left(\frac{2203.37}{200} + \frac{0.025}{200} \text{ cpm}\right)^{1/2}}{(0.204)(0.95)(0.70)(0.33)(5.66 \times 10^5 \text{ml})(2.22 \times 10^6 \text{dpm}/\mu Ci)}$$

$= 3.9 \times 10^{-8} \pm 1.2 \times 10^{-10} \mu Ci/ml$ (air concentration in target bay)

(2)

$$X_1^* = \frac{(3.9 \times 10^{-8} \pm 5.7 \times 10^{-8} + 4.6 \times 10^{-8} + 1.2 \times 10^{-8})}{4} \left(\frac{g}{0.36 \mu Ci}\right)$$

$(18276 \text{ ft}^3)(2.832 \times 10^4 \text{ ml/ft}^3) = 55 \pm 0.30$ grams aerosolized uranium in target bay

(3) $X_2^* = \{4.8 \times 10^{-9} \mu Ci/ml [\pi(121.9)^2(457.2)] + (4.2 \times 10^{-9} \mu Ci/ml) [\pi(121.9)^2(701)] + (4.4 \times 10^{-9} \mu Ci/ml) [\pi(121.9)^2(731.5)]\}\left(\frac{g}{0.36 \mu Ci}\right)$

$$X_2^* = [0.102448 \text{ Ci} + 0.137444 + 0.150253] \left(\frac{g}{0.36 \mu Ci}\right) = 1.08 \Rightarrow 1.1 \text{ gram}$$

(4) $X^* = 55g + 1.1g = 56.1 \Rightarrow 56 \text{grams}$

(5) $P_p = \frac{56g}{2270g} \times 100 = 2.467 = 2.5\%$

B. Particle Sizing Determination

Gross particulate alpha or beta activity for a given sample:

$$\mu Ci = \frac{NCPM \pm 2\left(\frac{R_{s+b}}{t_{s+b}} + \frac{R_b}{t_b}\right)^{1/2}}{(E)(Y)(F_{sa})(F_r)(2.22 \times 10^6 \text{dpm}/\mu Ci)}$$

MEAN SAMPLE RESULTS, IN GRAMS:

$$\bar{X}_i = \frac{\Sigma X}{n}\left(\frac{g}{0.36\mu Ci}\right)$$

where:

$\bar{X}_i$ = Sample mean

PERCENTAGE OF AEROSOLIZED DU IN APPLICABLE PARTICLE SIZE RANGE:

$$P_s = \left(\frac{\bar{X}_i}{\Sigma X_i}\right) 100$$

where:

P_s = Percent of aerosolized DU collected by the applicable impactor stage

MASS MEDIAN AERODYNAMIC DIAMETER (MMAD): The MMAD was derived from the graph of "Cumulative Percent Less Than Stated Size" versus "Particle Size" for each round and for the mean. The particle size geometric standard deviation (σ_g) is also obtained from the graph and is given by:

$$\sigma_g = \frac{84.13\% \text{ diameter}}{50\% \text{ diameter}} = \frac{50\% \text{ diameter}}{15.87\% \text{ diameter}}$$

SAMPLE CALCULATION:

Gross Particulate Alpha or Beta Activity For a Given Sample:

$$\frac{1091 \pm 2\left(\frac{1091.25}{200} + \frac{0.25}{200}\right)^{1/2}}{(0.206)(1.0)(0.70)\left(\frac{10}{300}\right)(2.22 \times 10^6 \text{dpm}/\mu Ci)} = 0.1022 \pm 0.000438\mu Ci$$

Mean Sample Results in Grams:

$$\bar{X}_i = \left(\frac{.1012 + .1022}{2}\right)\left(\frac{g}{0.36\mu Ci}\right) = 0.2825 \text{ grams}$$

Percentage of Aerosolized DU in Applicable Parted Size Range:

$$P_s = \left(\frac{0.2825}{2.7405}\right) 100 = 10.3\%$$

C. Amount of Uranium Collected by Range Ventilation System Prefilters

Total Particulate (Uranium and Non-uranium) Collected By a Prefilter:

$$P_{ti} = W_g - W_t$$

where:

P_{ti} = Total Particulate Collected

W_g = Gross Weight of Prefilter

W_t = Tare Weight of Prefilter

Fractional Percentage of Total Particulate Which is Uranium:

$$DU/g\ sample = \frac{NCPM \pm 2\left(\frac{R_{s+b}}{t_{s+b}} + \frac{R_b}{t_b}\right)^{1/2}}{(E)(G)(2.22 \times 10^6 dpm/\mu Ci)(0.36 \mu Ci/g)}$$

where:

G = Grams of Sample (Total Particulate) Analyzed

Total Uranium Collected By a Prefilter:

$$U_{ti} = P_{ti} \times DU/g\ sample$$

Total Uranium Collected By Prefilters:

$$U_t = \Sigma U_{ti}$$

Percentage of Penetrator Aerosolized:

$$P_p = \frac{U_t}{M_p} \times 100$$

SAMPLE CALCULATIONS:

Total Particulate Collected By A Prefilter:

P_{ti} = 4977g - 4686g = 291g

291g - 221g = 70g NET

NOTE: Used filter was weighed in a plastic bag to preclude contamination problems. The 221 grams used above is the weight of this 55-gallon plastic bag.

IV. ERROR ANALYSIS

A. General

Particle size and total aerosol samples were obtained beginning two minutes after firing. For this data to correspond to the period immediately after firing requires the assumption that the environment in the target ba and projectile flight tube did not change during the two minute interval after firing. An indeterminate amount of gravitational settling would occur during this period. The short duration of the wait after firing before sampling was such, however, that significant gravitational settling of only very large nonrespirable particles should occur. For practical application the data obtained are representative of the period immediately after firing. No error should be introduced by such uses of sample data. Users should consider whether the sampling periods used in these tests are applicable to their situation and requirements.

B. Estimation of Total Aerosolization

Error in the estimate of total uranium aerosolized as derived from the results of total particulate samples includes errors due to assumptions made and collection and analysis errors.

1. Errors Due to Assumptions Used:

The error resulting from the assumption of verticle dispersion in the target bay is indeterminate but should be comparatively small. The blast wave and heat resulting from impact of the penetrator with the target

provided stimuli for mixing, both in the horizontal and verticle planes. Additionally, the two minute waiting period after firing allowed time for cooling of the air resulting in further mixing.

The error resulting from projectile flight tube dispersion assumptions is insignificant. Results show that the amount of uranium released into the PFT is a maximum of about five percent of the total amount of uranium aerosolized. As such, the error associated with this measurement is inconsequential when compared to other potential errors.

2. Sample Collection Errors [4]

Errors in total volume of air sampled are limited to calibration errors, error in the timing of sample duration, and errors in reading the sampler meter scale (for Staplex samplers only). Using error estimate procedures specified in NRC Regulatory Guide total error in sample volume is estimated at six to twelve percent.

Calibration errors include three percent for the calibration standard, three to five percent for intrinsic error in reading the sampler meter scale, and one to five percent for error in reading the calibrator. These errors are applicable to calibration using a critical orifice and manometer with error ranges being a function of flow rate. Total calibration error is estimated to four to seven percent.

Error in the timing of sampling duration is about two percent.

Error estimates for reading the sampler meter scale of Staplex samplers is three to five percent for sampling rates of 30 to 20 cubic feet per minute, respectively. Maximum total error would be about seven percent when both initial and final flow rate readings are included.

Minimal errors should be introduced by averaging flow rates of Staplex errors due to the short sample duration used and resultant comparatively small drop in flow rates.

3. Analysis Errors

General: Sample analysis errors include statistical errors inherent in radiation counting, errors due to filter fraction, sample self-absorption, collection efficiency, and counting efficiency determination. The total analysis error is estimated at fifteen to thirty percent.

Radiation counting errors are from less than one percent to two percent of the applicable count at the ninety-five percent confidence level.

4. CALIBRATION AND ERROR LIMITS OF AIR SAMPLING INSTRUMENTS FOR TOTAL VOLUME OF AIR SAMPLED, Draft Regulatory Guide, U.S. Nuclear Commission, Washington, D.C., October, 1979.

The lower end of this range is for samples collected in the target bay while the upper end of the range is for lower activity PFT samples.

Filter fraction error is estimated to be about two percent.

Collection efficiency errors are less than 0.1 percent for glass fiber filters used in the PFT. The error in collection efficiency for the cellulose filters used in the target bay is a function of particle size, linear velocity through the filter, and total mass of material collected and is estimated to be less than five percent.

Errors in determination of counting efficiency include those due to calibration source counting and the use of Th-232 calibration source in lieu of a U-238 standard. These errors are less than 0.1 percent and five percent, respectively.

Alpha self-absorption of thirty percent was assumed for all samples. This value is an estimate supplied by a cellulose filter manufacturer and was used for both cellulose and glass fiber filters due to the lack of a more accurate estimate. American National Standards Institute (ANSI) Standard N13.1-1969 states that self-absorption is less for glass fiber filters than cellulose based filters. As such, use of this value could result in a significant but indeterminate overestimate of the actual amount of airborne uranium in the PFT.

Self-absorption within the sample (as opposed to absorption in the filter media) is indeterminate and could be significant due to the comparatively large volume of uranium collected on the filters and the high density of uranium. Analysis of the alpha to beta ratios for air samples indicatesthat the self-absorption rates used probably overcompensate and reflect higher levels of airborne uranium than are actually present. The average error, based on alpha to beta ratios, is about twenty percent.

C. Particle Sizing Determination

1. General

Particle size samples were obtained during the period two to three minutes after firing. For this data to correspond to the actual particle size distribution present immediately after firing requires the assumption that the two distributions are equivalent. An indeterminate amount of gravitational settling, would occur during the two minute wait after firing. The length of this duration is such, however, that significant settling of only very large, nonrespirable particles would occur. As such, for practical uses the particle size distribution during the two to three minute sampling period is equivalent to that present immediately after firing. The impact of particle agglomeration was not determined and could be significant.

2. Material Collected By Ventilation System Filters

Estimation of the total aerosolization by analysis of uranium collected by the range ventilation system was accomplished as a cross-check on total particulate data. These data should not be used in lieu of other data due to the extent of the systematic error. The total error is estimated at greater than one-hundred percent.

Estimation of the total aerosol as derived from the amount of uranium collected by the range ventilation system filters is subject to errors due to assumptions made, weighing filters, and those resulting from sample collection and analysis.

This estimation assumes the following: 1) that all material which was aerosolized was collected by the ventilation system filters; 2) that no moisture was collected by the filters; 3) that samples collected from each filter were representative of the dispersion on that filter (i.e., that the total particulate and uranium were evenly dispersed across the face of the filter); 4) that the percentage of mass which was uranium was the same through the entire depth of the filter. No attempt was made to account for material which was removed from the ventilation system by gravitational settling or impingement, to accurately ascertain the actual nature of the uranium dispersion of the face of or through the depth of the filters, or to account for the resuspension of uranium deposited in the ventilation system by prior firings. The error due to the assumptions made is indeterminate but substantial.

V. RESULTS

A. Estimation of Total Aerosolization

Tables 2 and 3 show the airborne concentration of depleted uranium in the Target Bay and Projectile Flight Tube, respectively. Specific sampling locations for these data are listed in Figure 2, page 14. The total amount of uranium which was airborne during the applicable sampling period is listed in Tables 4 through 6. Estimation of the total aerosol, using the ventilation system prefilters, resulted in the data noted in Table 7.

B. Particle Size Data

Results of particle size impactor samples for each round and the resultant graph are listed in Tables 8 through 15, Rounds 2 through 9, respectively. Data reflected in Table 16 are for the means of Rounds 3 through 9. Round 2 data is not included in mean determination as the total amount of particulate per stage exceeded the 75 milligram limit suggested by the particle sizing impactor manufacturer.

Table 17 is a summary of BRL particle size impactor results. Results of the contractor analysis of impactor samples is included in Appendix A.

TABLE 2. RESULTS OF TARGET BAY
TOTAL PARTICULATE AIR SAMPLES

ROUND	ACTIVITY AT SAMPLING LOCATIONS[1] (µCi/ml)			
	A	B	C	MEAN (By Round)
1	4.6×10^{-8}	5.7×10^{-8}	3.9×10^{-8}	4.7×10^{-8}
2	6.1×10^{-8}	7.4×10^{-8}	8.6×10^{-8}	7.4×10^{-8}
3	4.9×10^{-8}	4.5×10^{-8}	3.4×10^{-8}	4.3×10^{-8}
4	4.5×10^{-8}	5.7×10^{-8}	3.0×10^{-8}	4.4×10^{-8}
5	5.8×10^{-8}	SEE NOTE 2	3.2×10^{-8}	4.5×10^{-8}
6	2.9×10^{-8}	2.7×10^{-8}	1.2×10^{-8}	2.3×10^{-8}
7	7.5×10^{-8}	8.6×10^{-8}	7.8×10^{-8}	8.0×10^{-8}
8	5.5×10^{-8}	3.0×10^{-8}	3.3×10^{-8}	3.9×10^{-8}
9	3.2×10^{-8}	2.0×10^{-8}	2.8×10^{-8}	2.7×10^{-8}
Mean (By Location)	5.0×10^{-8}	5.0×10^{-8}	4.1×10^{-8}	4.7×10^{-8}

NOTES: (1) *For locations refer to Figure 2.*

(2) *Data not obtained due to penetration of sampler by secondary spall.*

(3) *Data was obtained at Location "D" for Round 1 only (Sampler was destroyed in Round 2). This sample was* 1.2×10^{-8} *µCi/ml.*

(4) *The mean of all total particulate samples obtained was* 4.7×10^{-8} *µCi/ml.*

(5) *The range ventilation system was in operations during Round 3.*

TABLE 3. RESULTS OF PROJECTILE FLIGHT TUBE TOTAL PARTICULATE AIR SAMPLES

ROUND	ACTIVITY AT SAMPLING LOCATIONS[1] (µCi/ml)		
	E	F	G
1	4.8×10^{-9}	4.2×10^{-9}	4.4×10^{-9}
2	4.4×10^{-9}	4.6×10^{-9}	1.6×10^{-9}
3[2]	4.1×10^{-9}	8.7×10^{-11}	2.0×10^{-11}
4	9.1×10^{-9}	2.0×10^{-9}	7.0×10^{-11}
5	1.3×10^{-8}	2.5×10^{-9}	1.9×10^{-10}
6	1.6×10^{-8}	1.1×10^{-8}	8.2×10^{-9}
7	1.5×10^{-8}	1.3×10^{-8}	5.6×10^{-10}
8	1.9×10^{-8}	6.6×10^{-9}	3.7×10^{-10}
9	1.9×10^{-8}	8.7×10^{-9}	4.4×10^{-10}
Mean	1.3×10^{-8}	6.6×10^{-9}	2.0×10^{-9}

NOTES: *(1) For locations refer to Figure 2.*

(2) The range ventilation system was in operations during Round 3. As such, means do not include round 3 data.

TABLE 4. TOTAL AMOUNT OF URANIUM AEROSOL IN TARGET BAY

ROUND	AVERAGE AIR CONCENTRATION (μCi/ml)	TOTAL AMOUNT OF URANIUM AEROSOL (grams)	PERCENTAGE OF PENETRATOR AS AEROSOL IN TARGET BAY
1	4.7×10^{-8}	67	3.0
2	7.4×10^{-8}	106	4.7
3	4.3×10^{-8}	62	2.7
4	4.4×10^{-8}	63	2.8
5	4.5×10^{-8}	65	2.9
6	2.3×10^{-8}	33	1.5
7	8.0×10^{-8}	115	5.1
8	3.9×10^{-8}	56	2.5
9	2.7×10^{-8}	39	1.7
Mean	4.7×10^{-8}	67	3.0

TABLE 5. TOTAL AMOUNT OF URANIUM AEROSOL IN THE PROJECTILE FLIGHT TUBE

ROUNDS	0 to 4.6 meters (0 to 15 feet) (grams)	4.6 to 11.6 meters (15 to 38 feet) (grams)	11.6 to 18.9 meters (38 to 62 feet) (grams)	TOTAL (grams)
1	0.28	0.38	0.42	1.1
2	0.26	0.42	0.15	0.83
3	0.24	0.0079	0.0019	0.25
4	0.54	0.18	0.0066	0.73
5	0.77	0.23	0.18	1.2
6	0.95	1.0	0.078	2.0
7	0.89	1.2	0.053	2.1
8	1.1	0.94	0.035	2.1
9	1.1	1.3	0.042	2.4
Mean(1)	0.74	0.71	0.12	1.6

NOTES: (1) Mean excludes Round 3 data which was obtained with the ventilation system operating and thus is not comparable to other data.

TABLE 6. TOTAL AMOUNT OF URANIUM AEROSOL

ROUND	AMOUNT OF URANIUM IN TARGET BAY (grams)	AMOUNT OF URANIUM IN PROJECTILE FLIGHT TUBE (grams)	TOTAL AMOUNT OF URANIUM AEROSOLIZED (grams)	PERCENT OF PENETRATOR AEROSOLIZED
1	67	1.1	68	3.0
2	110	0.83	110	4.8
3	62	0.25	62	2.7
4	63	0.73	64	2.8
5	65	1.2	66	2.9
6	33	2.0	35	1.5
7	120	2.1	120	5.3
8	56	2.1	58	2.6
9	39	2.4	41	1.8
Mean	67	1.4	69	3.0

NOTES: (1) All data are rounded to two significant figures.

TABLE 7. MATERIAL COLLECTED BY VENTILATION SYSTEM PREFILTERS

95 PERCENT EFFICIENCY PREFILTERS:

	TOTAL MASS COLLECTED (grams)	MASS URANIUM PER TOTAL MASS COLLECTED		URANIUM COLLECTED (grams)
1	106	.642		68
2	70	.494		35
3	124	.270		33
4	119	.648		77
5	102	.798		81
6	108	.290		31
			TOTAL	325

30 PERCENT EFFICIENCY PREFILTERS:

1	114	.232		26
2	114	.198		23
3	97	.207		20
4	114	.222		25
5	97	.266		26
6	97	.1785		17
			TOTAL	137

Total Uranium Collected By Prefilters For Two Rounds:
462 grams => 460 grams

Total Uranium Collected By Prefilters Per Round: Assumed To Be 230 grams

Percentage of Penetrator Aerosolized: 10 Percent

TABLE 8 ROUND 2 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	281/284	282.5	10.3	89.7
3.3-7.0	559/467	513.0	18.7	71.0
2.0-3.3	242/249	245.5	9.0	62.0
1.1-2.0	216/243	229.5	8.4	53.6
0-1.1	1510/1430	1470	53.6	0

SAMPLER B

>7.0	235/237	236.0	7.1	92.9
3.3-7.0	581/661	621.0	18.7	74.2
2.0-3.3	206/245	225.5	6.8	67.4
1.1-2.0	176/176	176.0	5.3	62.1
0-1.1	1980/2140	2060	62.1	0

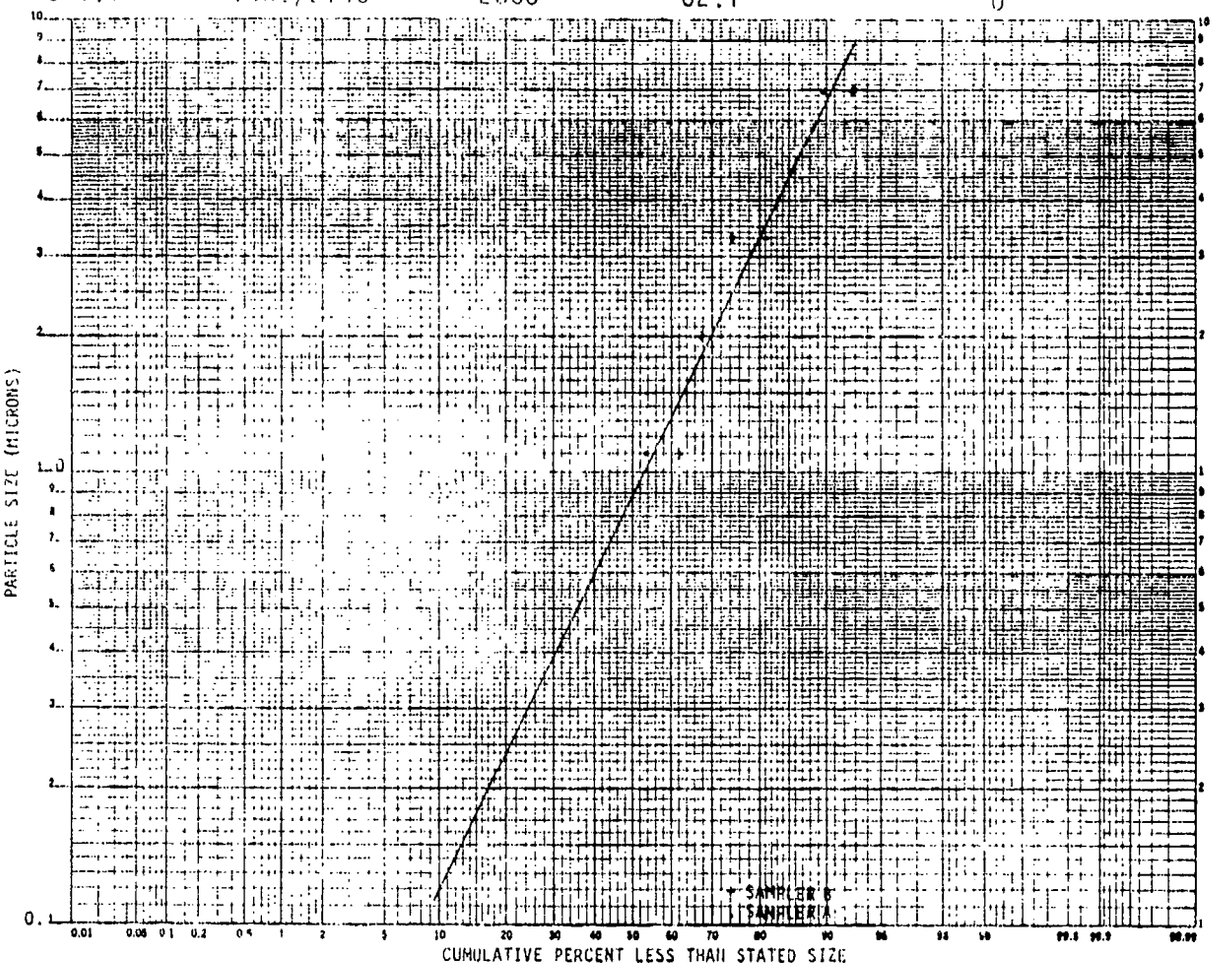


TABLE 9 ROUND 3 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	19.1/26.2	22.66	27.0	73.0
3.3-7.0	8.53/9.02	8.775	10.4	62.6
2.0-3.3	6.87/6.46	6.665	7.9	54.7
1.1-2.0	11.14/9.29	10.34	12.3	42.4
0-1.1	36.3/35.0	35.65	42.4	0

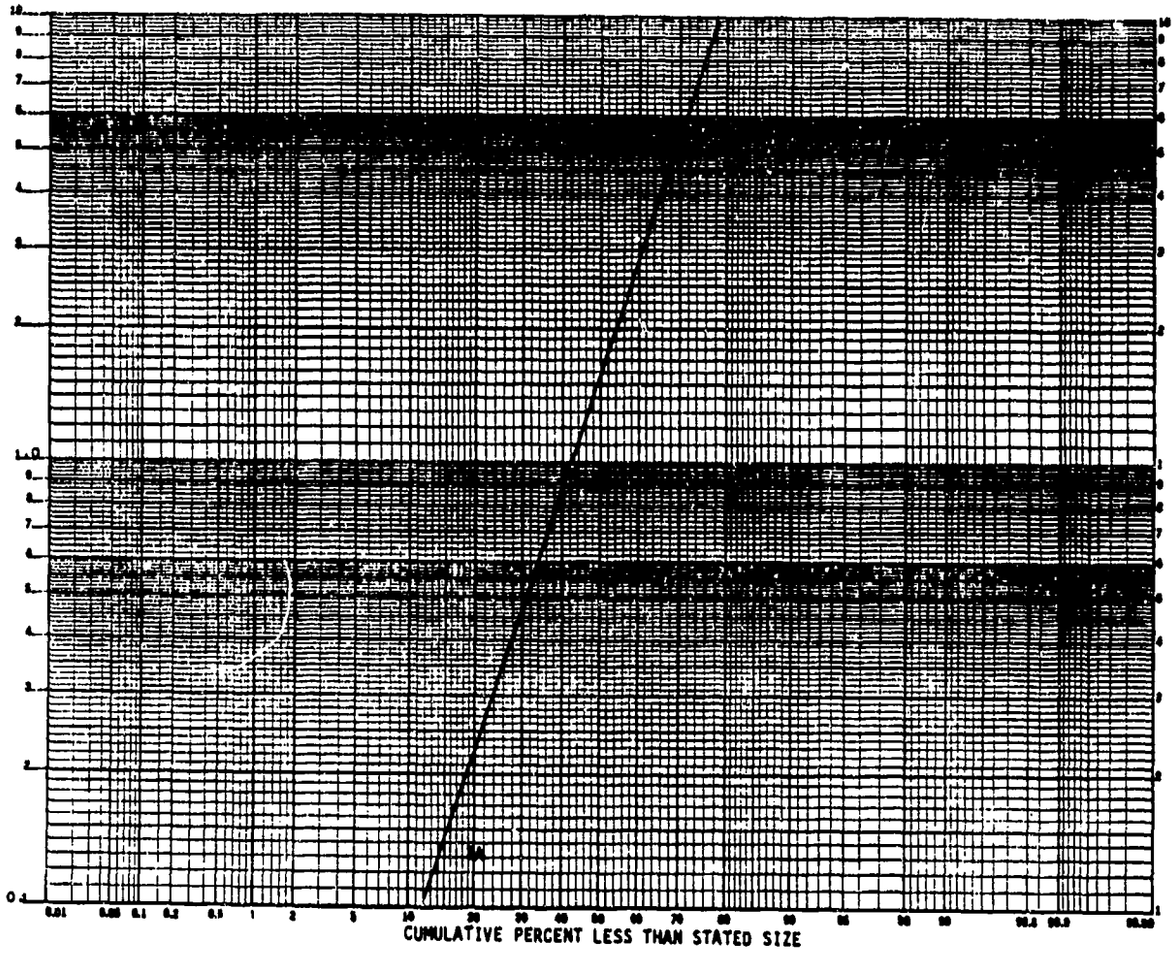


TABLE 10 ROUND 4 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	33.5/44.1	38.80	25.5	74.5
3.3-7.0	18.4/16.7	17.5	11.5	63.0
2.0-3.3	12.2/11.4	11.80	7.7	55.3
1.1-2.0	15.8/15.1	15.45	10.1	45.2
0-1.1	68.0/69.7	68.85	45.2	0

SAMPLER B

>7.0	47.6/53.6	50.60	29.9	70.1
3.3-7.0	21.8/23.2	22.50	13.3	56.8
2.0-3.3	12.2/11.4	11.80	7.0	49.8
1.1-2.0	15.8/15.1	15.45	9.1	40.7
0-1.1	68.0/69.7	68.85	40.7	0

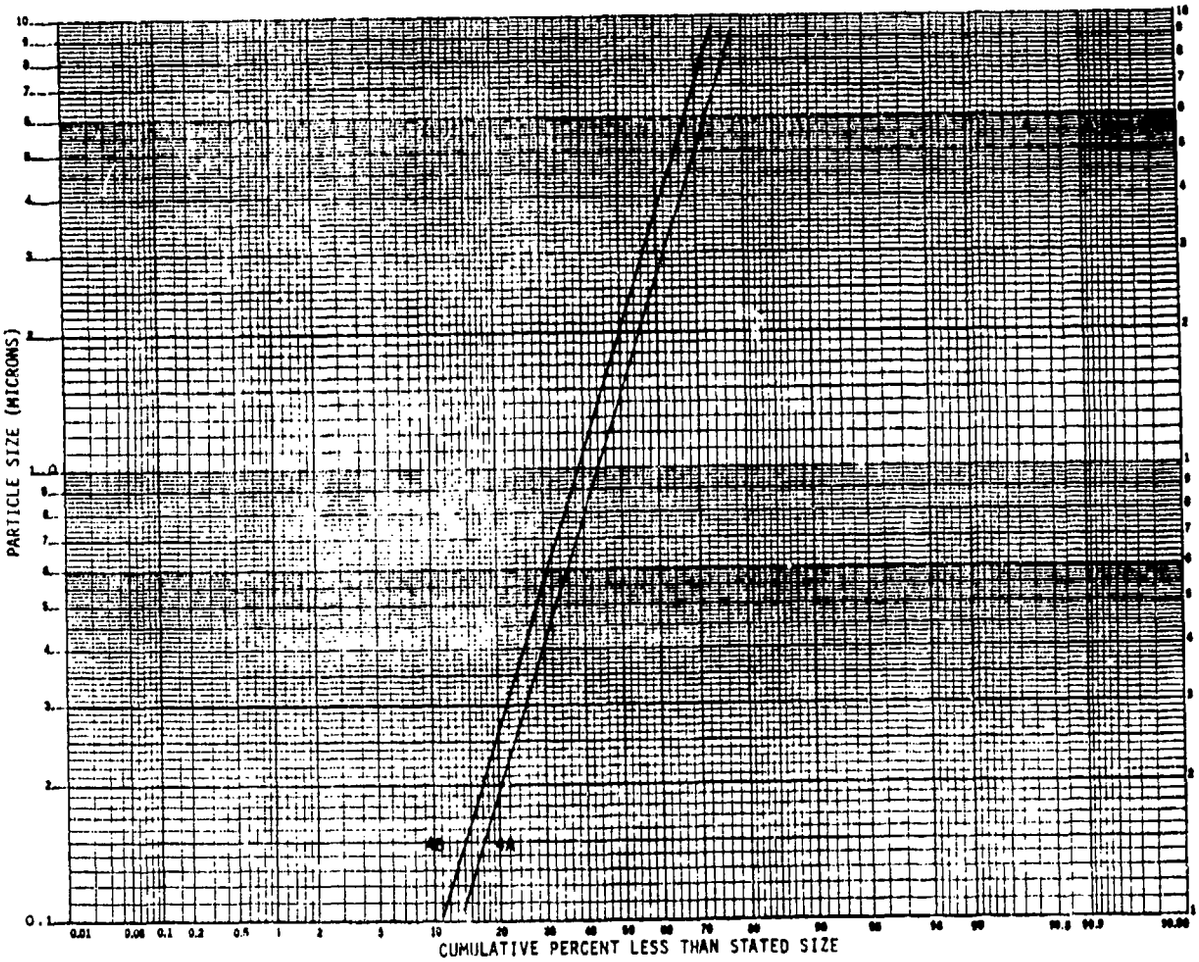


TABLE 11 ROUND 5 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	64.6/39.3	51.95	28.1	71.9
3.3-7.0	18.3/21.3	19.80	10.7	61.2
2.0-3.3	12.7/11.7	12.20	6.6	54.6
1.1-2.0	14.1/14.3	14.20	7.7	46.9
0-1.1	84.2/89.2	86.70	46.9	0

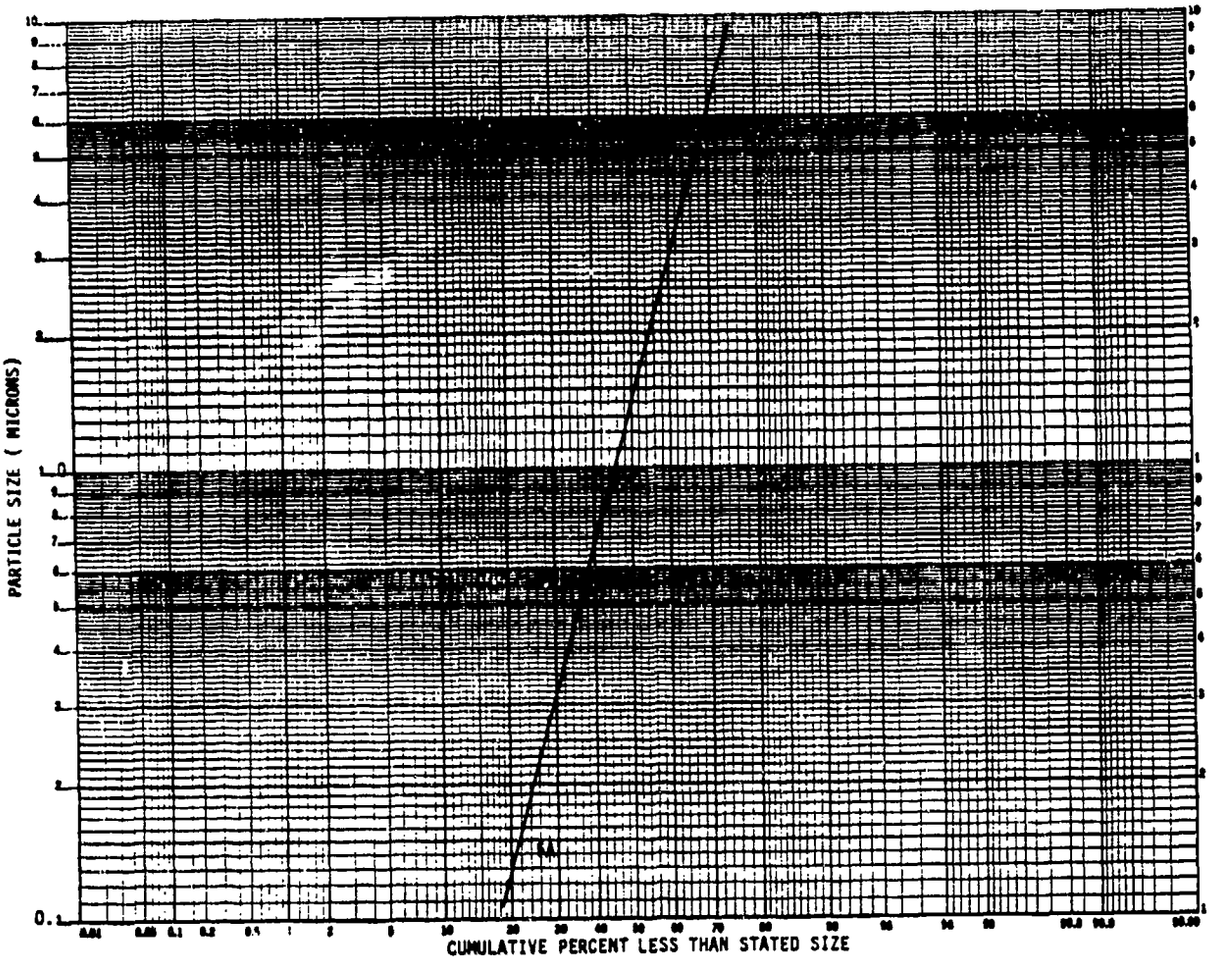


TABLE 12 ROUND 6 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	35.1/22.9	29.0	31.8	68.2
3.3-7.0	9.19/10.0	9.60	10.5	57.7
2.0-3.3	6.52/6.39	6.46	7.1	50.6
1.1-2.0	7.19/7.40	7.30	8.0	42.6
0-1.1	37.5/40.1	38.80	42.6	0

SAMPLER B

>7.0	24.4/19.8	22.1	26.3	73.7
3.3-7.0	8.92/9.03	8.98	10.7	63.0
2.0-3.3	6.33/6.19	6.26	7.5	55.5
1.1-2.0	7.57/7.58	7.58	9.0	46.5
0-1.1	38.9/39.2	39.05	46.5	0

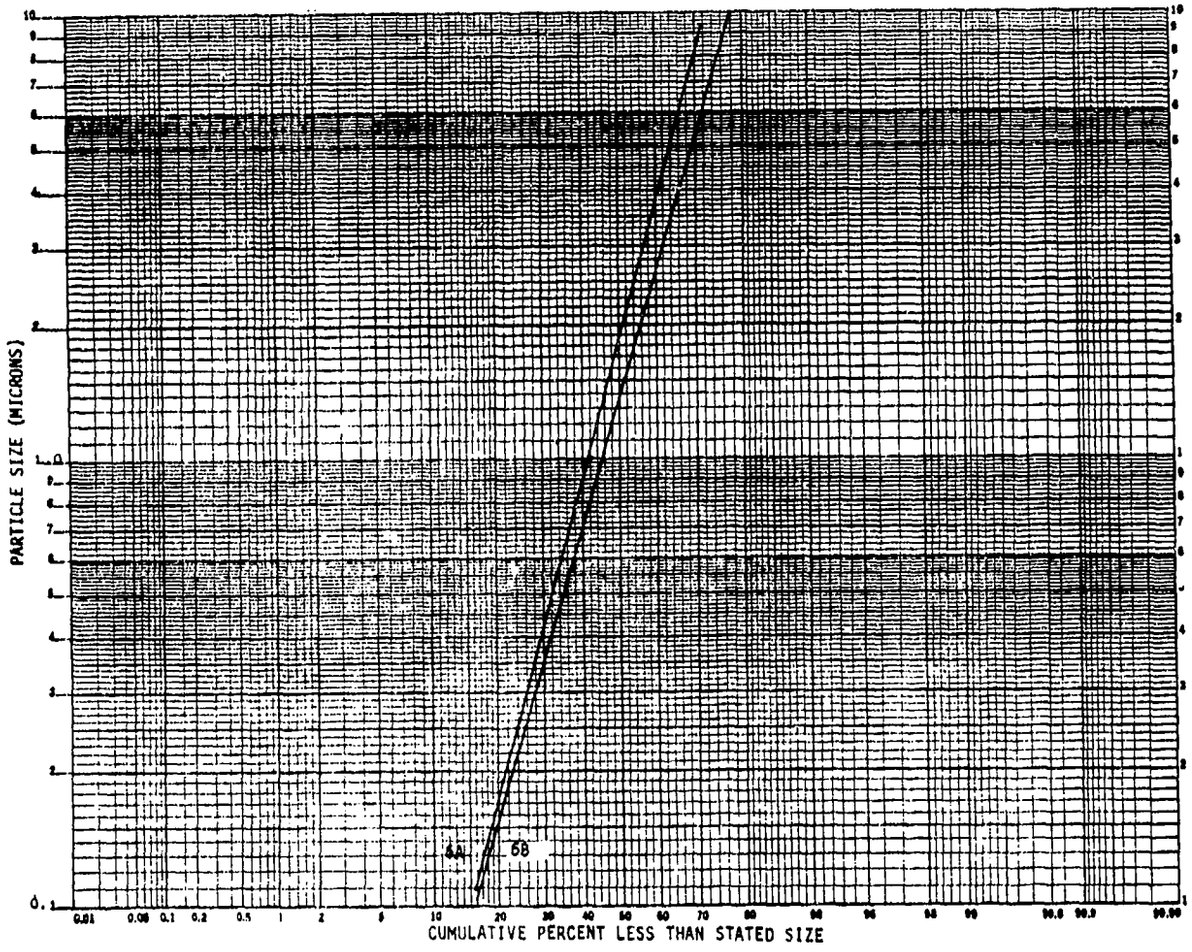


TABLE 13 ROUND 7 PARTICLE SIZE DATA

SAMPLER B

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	104/83.0	93.5	27.9	72.1
3.3-7.0	36.4/32.8	34.60	10.3	61.8
2.0-3.3	24.4/24.0	24.20	7.2	54.6
1.1-2.0	29.1/26.8	27.95	8.3	46.3
0-1.1	153/158	155.5	46.3	0

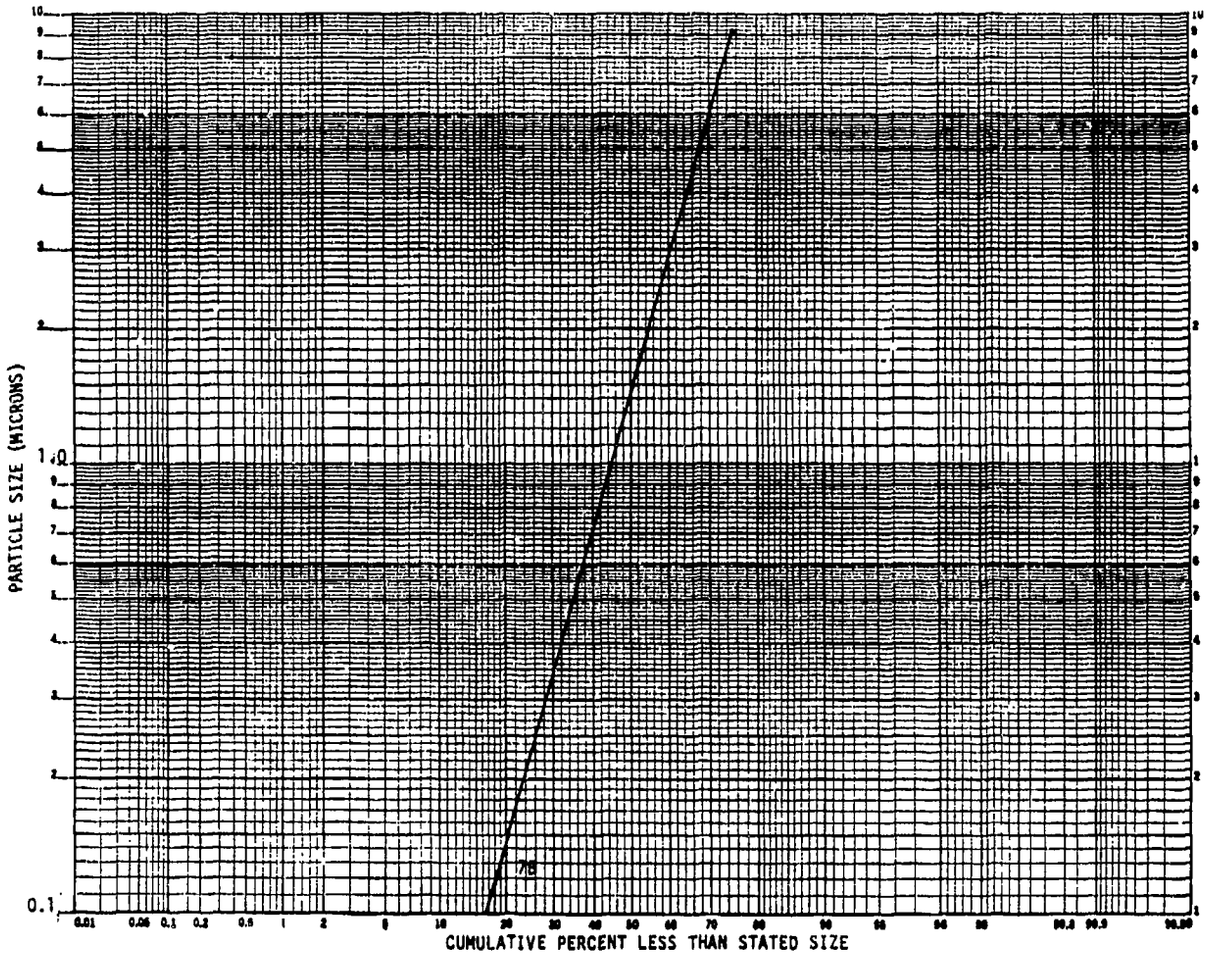


TABLE 14 ROUND 8 PARTICLE SIZE DATA

SAMPLER B

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	45.9/33.9	39.90	25.6	74.4
3.3-7.0	17.9/18.4	18.15	11.7	62.7
2.0-3.3	12.6/11.7	12.15	7.8	54.9
1.1-2.0	16.1/15.0	15.55	10.0	44.9
0-1.1	69.9/70.2	70.05	44.9	0

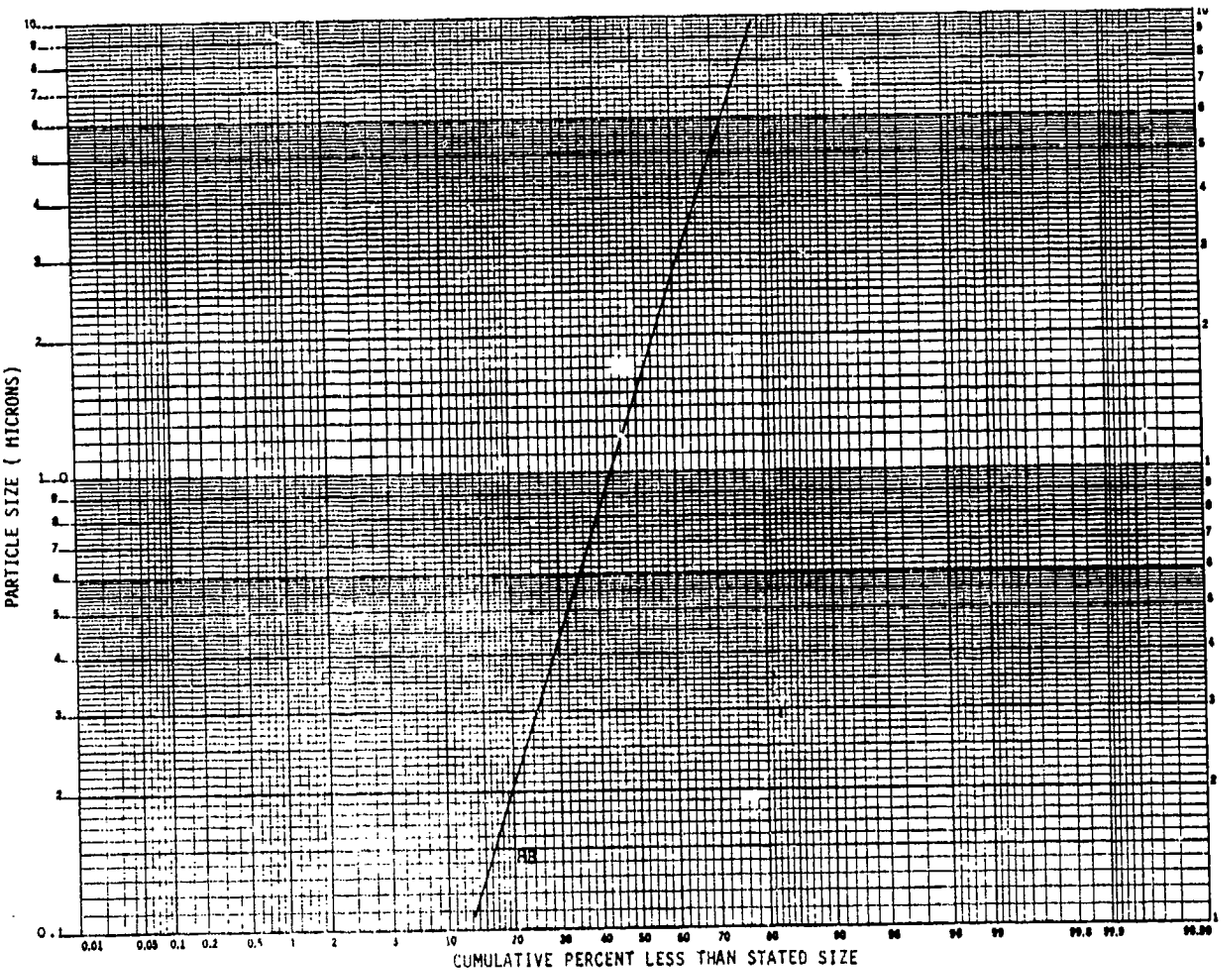


TABLE 15 ROUND 9 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	RESULTS OF SPLIT SAMPLES (mg)	MEAN SAMPLE MASS (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	28.8/36.1	32.4	28.3	71.7
3.3-7.0	14.6/11.8	13.2	11.5	60.2
2.0-3.3	8.19/7.75	7.97	6.9	53.3
1.1-2.0	10.1/12.2	11.2	9.8	43.5
0-1.1	47.9/51.9	49.9	43.5	0

SAMPLER B

>7.0	40.8	30.8	30.1	69.9
3.3-7.0	12.0/14.1	13.0	12.8	57.1
2.0-3.3	6.32/6.37	6.34	6.2	50.9
1.1-2.0	8.52/8.60	8.56	8.4	42.5
0-1.1	47.5/39.6	43.6	42.5	0

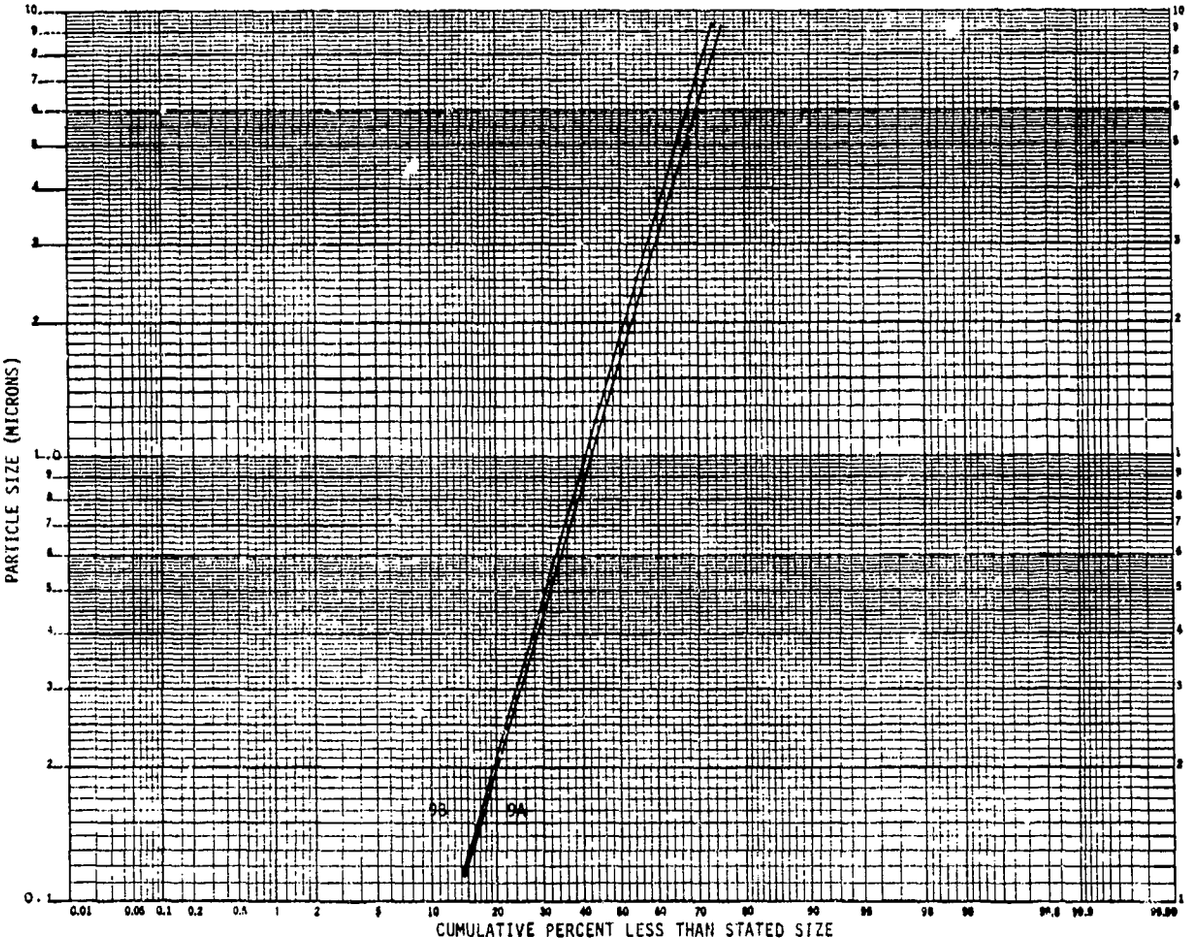


TABLE 16 MEAN PARTICLE SIZE DATA
(ROUNDS 3 THROUGH 8)

PARTICLE DIAMETER (microns)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	28.0	72.1
3.3-7.0	11.4	60.7
2.0-3.3	7.2	53.5
1.1-2.0	9.3	44.2
0-1.1	44.2	0

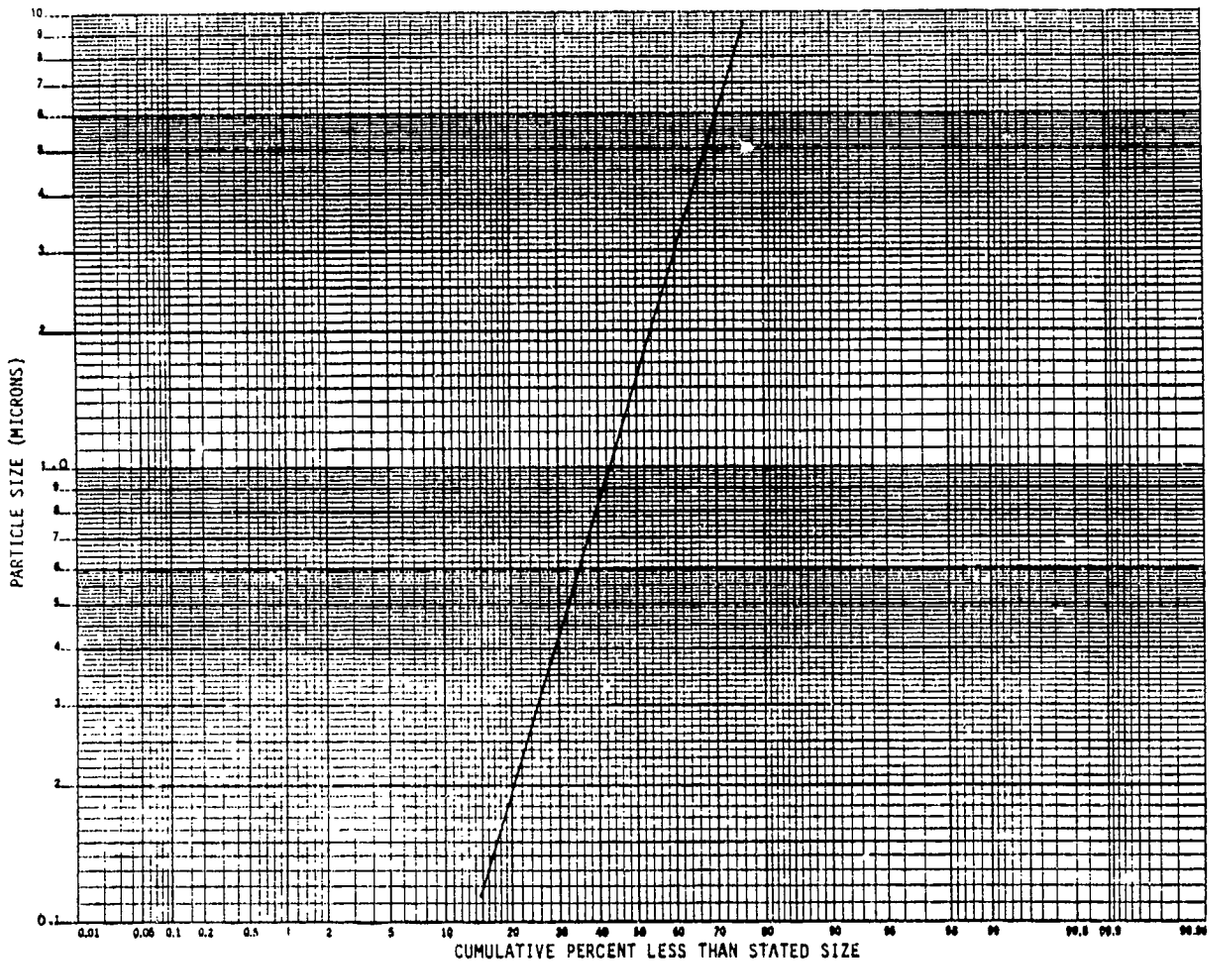


TABLE 17 SUMMARY OF BRL PARTICLE SIZE DATA

ROUND SAMPLER	PERCENT IN APPLICABLE SIZE RANGE >7.0 microns	3.3 - 7.0 microns	2.0 - 3.3 microns	1.1 - 2.0 microns	<1.1 microns	MMAD[1] microns	σg[2] microns
2A	10.3	18.7	9.0	8.4	53.6	(5)	(5)
2B	7.1	18.7	6.8	5.3	62.1	(5)	(5)
3A	27.0	10.4	7.9	12.3	42.4	1.6	10
4A	25.5	11.5	7.7	10.1	45.2	1.5	11
4B	29.9	13.3	7.0	9.1	40.7	2.0	11
5A	28.1	10.7	6.6	7.7	46.9	1.4	17
6A	31.8	10.5	7.1	8.0	42.6	1.9	16
6B	26.3	10.7	7.5	9.0	46.5	1.4	13
7B	27.9	10.3	7.2	8.3	46.3	1.5	15
8B	25.6	11.7	7.8	10.0	44.9	1.5	12
9A	28.3	11.5	6.9	9.8	43.5	1.7	12
9B	30.1	12.8	6.2	8.4	42.5	1.9	13
Mean (3)(4)	28.0	11.4	7.2	9.3	44.2	1.6	13

(1) Mass mean aerodynamic diameter

(2) Standard geometric deviation

(3) Values of MMAD and σg for the mean are derived from the resultant curve, not as the mean of other MMAD and σg data.

Continuation of TABLE 17 SUMMARY OF BRL PARTICLE SIZE DATA

(4) Mean data excludes Round 2 as the sample mass obtained in Round 2 is believed to have exceeded sampler capacity.

(5) Sampling period for Rourd 2 was two to four minutes after firing. Period sampled was two to three minutes after firing for all other rounds.

C. Summary of Results

Particle size data for the period two to three minutes after firing reflects an average mass mean aerodynamic diameter of 1.6 microns with a standard geometric deviation of 13 microns. Specific particle size data is as follows (for Rounds 3 through 9).

SUMMARY OF PARTICLE SIZE DATA

PARTICLE DIAMETER (microns)	RANGE (percent)	MEAN (percent)	STANDARD DEVIATION (percent)
>7.0	26-32	28.1	1.9
3.3-7.0	10-13	11.3	0.94
2.0-3.3	6.6-7.9	7.2	0.49
1.1-2.0	7.7-12.3	9.3	1.2
0-1.1	41-47	44.2	1.9

Total particulate data indicate that 1.5 to 5.3 percent of the penetrator was airborne during the period from two to three minutes after firing. The average percentage of penetrator aerosolized was 3.0 ± 2.4 at the ninety-five percent confidence level.

VI CONCLUSION

A. Data reflects that about three percent of a penetrator was airborne during the sampling period (two to three minutes after firing). Allowing for error, it can be concluded with reasonable certainty that less than ten percent of the penetrator was aerosolized. This contradicts findings of about seventy percent aerosolization for the XM774 by Battelle Pacific Northwest Laboratory. It is consistent with previous data obtained by BRL for small caliber DU penetrators and with mass balance studies at BRL's Transonic Range.

B. Particle sizing studies reflect an average mass mean aerodynamic diameter of 1.6 microns with a geometric standard deviation of 13 microns. Of the material airborne, approximately seventy percent was less than 7.0 microns and could be considered respirable. (Using Figure 51, ICRP Report 30, Errata, this particle size distribution would dictate that about seventy-two percent of the airborne material was respirable.) Although results indicate that the particle size distrbution of the DU aerosol generated approximates a log-normal distribution, it is significantly different from the distribution utilized in establishing regulatory limits for airborne radioactive materials.

C. This study introduced many questions regarding the nature of the aerosol generated by hard impact testing of DU penetrators. For example: Does the percentage of penetrator and particle size distribution change significantly when the penetrator mass, velocity or length to diameter ratio are varied? Was a significant amount of aerosol generated by impact of secondary spall with the target backstop? As a result of these questions, it is anticipated that additional tests will be conducted by BRL Operations Safety and Health Physics Division as personnel and budget restrictions permit.

APPENDIX A

CONTRACTOR ANALYSIS RESULTS

A total of 86 samples were submitted to Radiation Management Corporation (RMC) for their analysis. Seventy-eight (78) of these were split samples (divided into halves and submitted as individual samples) of 32 impactor and seven (7) total particulate samples.

These samples were analyzed by RMC for total uranium using standard fluorometric procedures. Results of RMC analysis of splits reflected significant disparity for individual samples. These errors probably resulted from not maintaining a constant sample size and quantitative transfer procedures.

RMC data is included for individual evaluation and interpretation by users of this report and for comparison with results obtained by BRL Operations Safety and Health Physics Division. RMC data is not utilized in deriving conclusions.

TABLE A-1 COMPARISON OF BRL
AND RMC MEAN PARTICLE SIZE DATA

	MMAD (microns)	σ_g
BRL	1.6	13
RMC	1.4	24

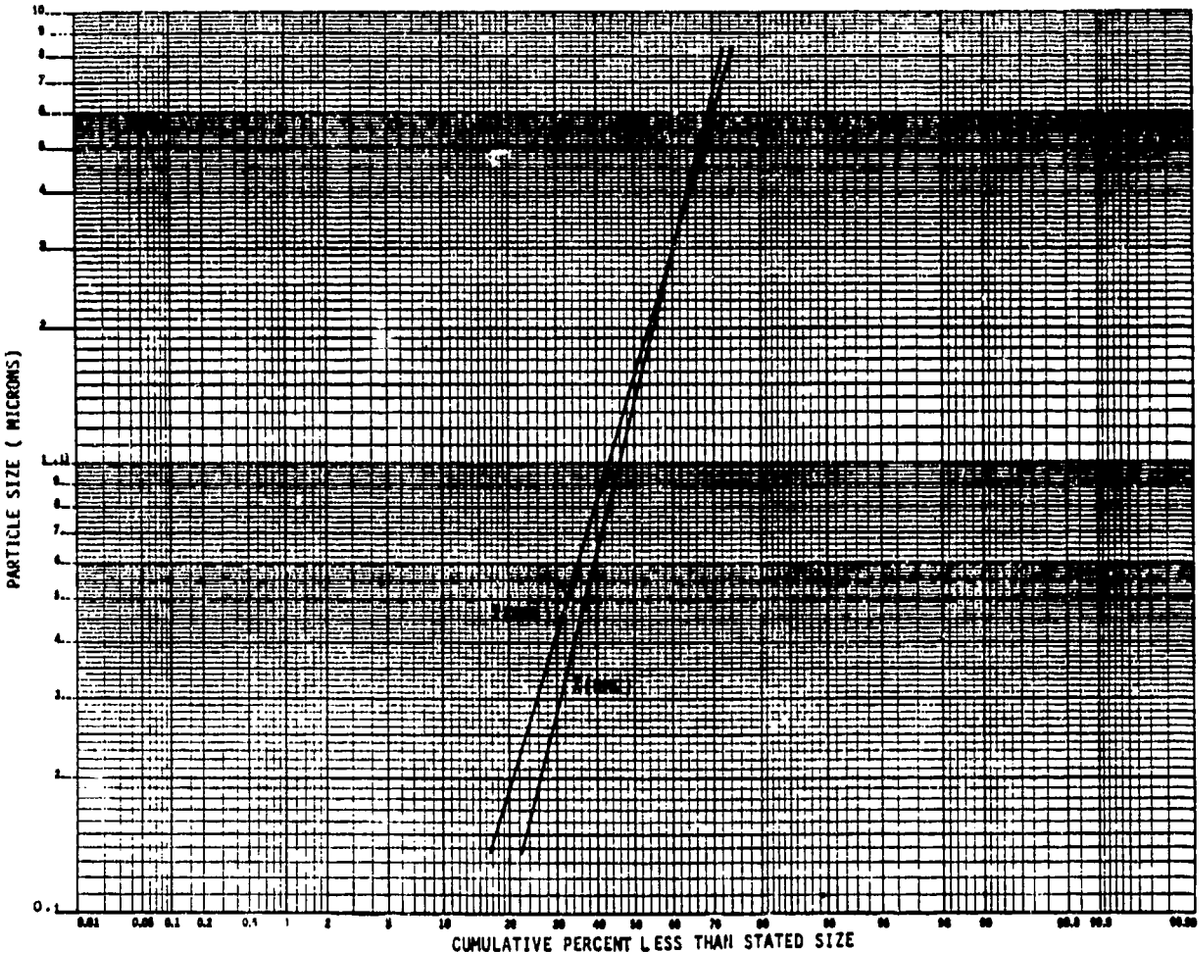


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TABLE A-2

RMC ANALYSIS, ROUND 3 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	SPLIT SAMPLE RESULTS (mg)	SAMPLE MEAN (mg)	TOTAL MASS ON FILTER (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	11.5/4.68	8.09	32.4	41.9	58.0
3.3-7.0	1.85/1.15	1.50	5.98	7.74	50.3
2.0-3.3	0.978/0.703	0.840	3.36	4.35	45.9
1.1-2.0	1.82/1.43	1.62	6.50	8.42	37.5
0-1.1	14.5	14.5	29.0	37.5	0

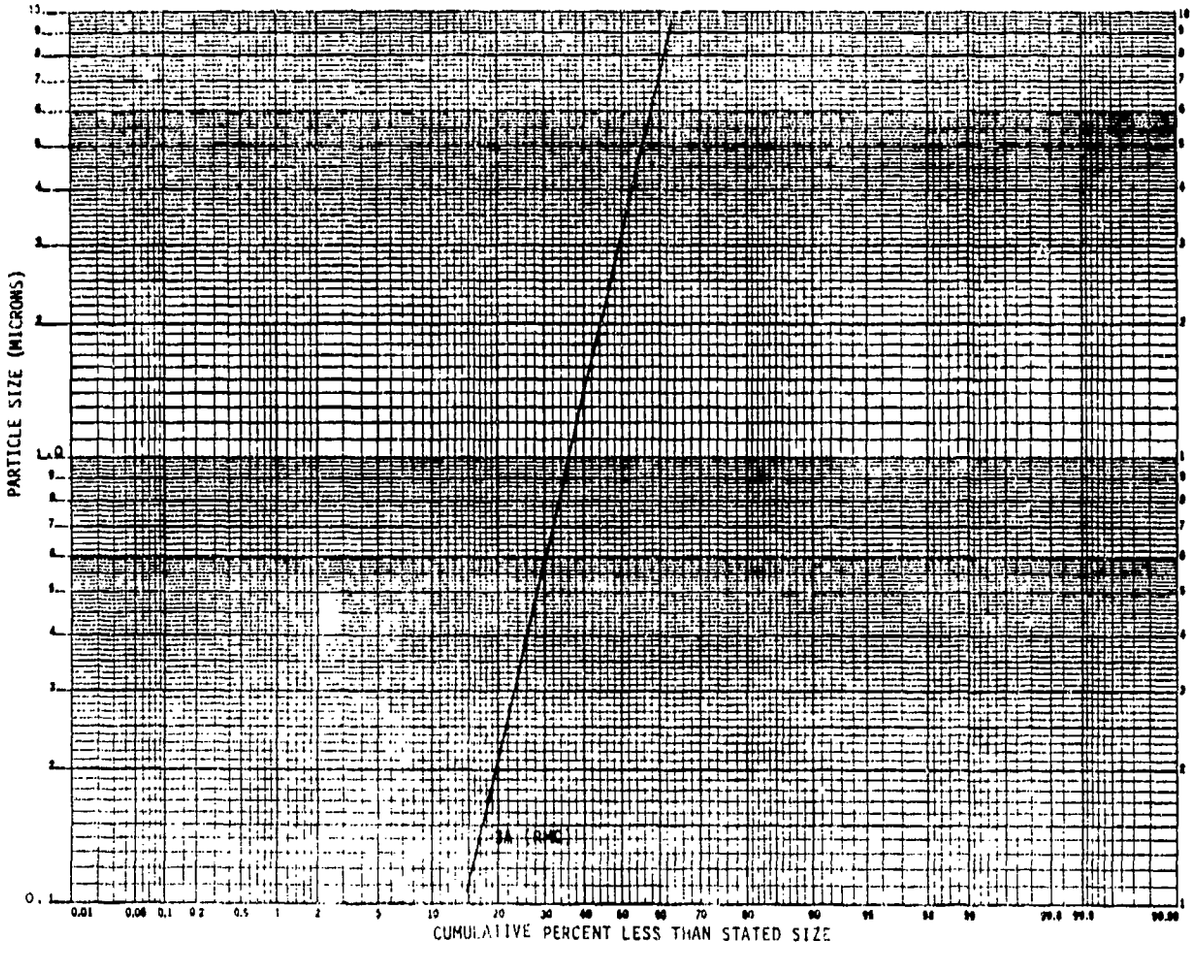

TABLE A-3

RMC ANALYSIS, ROUND 4 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	SPLIT SAMPLE RESULTS (mg)	SAMPLE MEAN (mg)	TOTAL MASS ON FILTER (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	9.45/20.8	15.12	60.5	43.9	56.1
3.3-7.0	1.73/2.22	1.98	7.90	5.73	50.4
2.0-3.3	1.86	2.96	11.84	8.59	41.8
1.1-2.0	1.38/0.824	1.10	4.41	3.20	38.6
0-1.1	26.6	26.6	53.2	38.6	0

SAMPLER B

>7.0	11.8/8.75	10.28	41.1	41.1	58.8
3.3-7.0	4.35/4.10	4.22	16.9	16.9	41.9
2.0-3.3	1.74/1.74	1.74	6.96	6.97	34.9
1.1-2.0	2.43/2.43	2.43	9.72	9.73	25.2
0-1.1	12.6	12.6	25.2	25.2	0

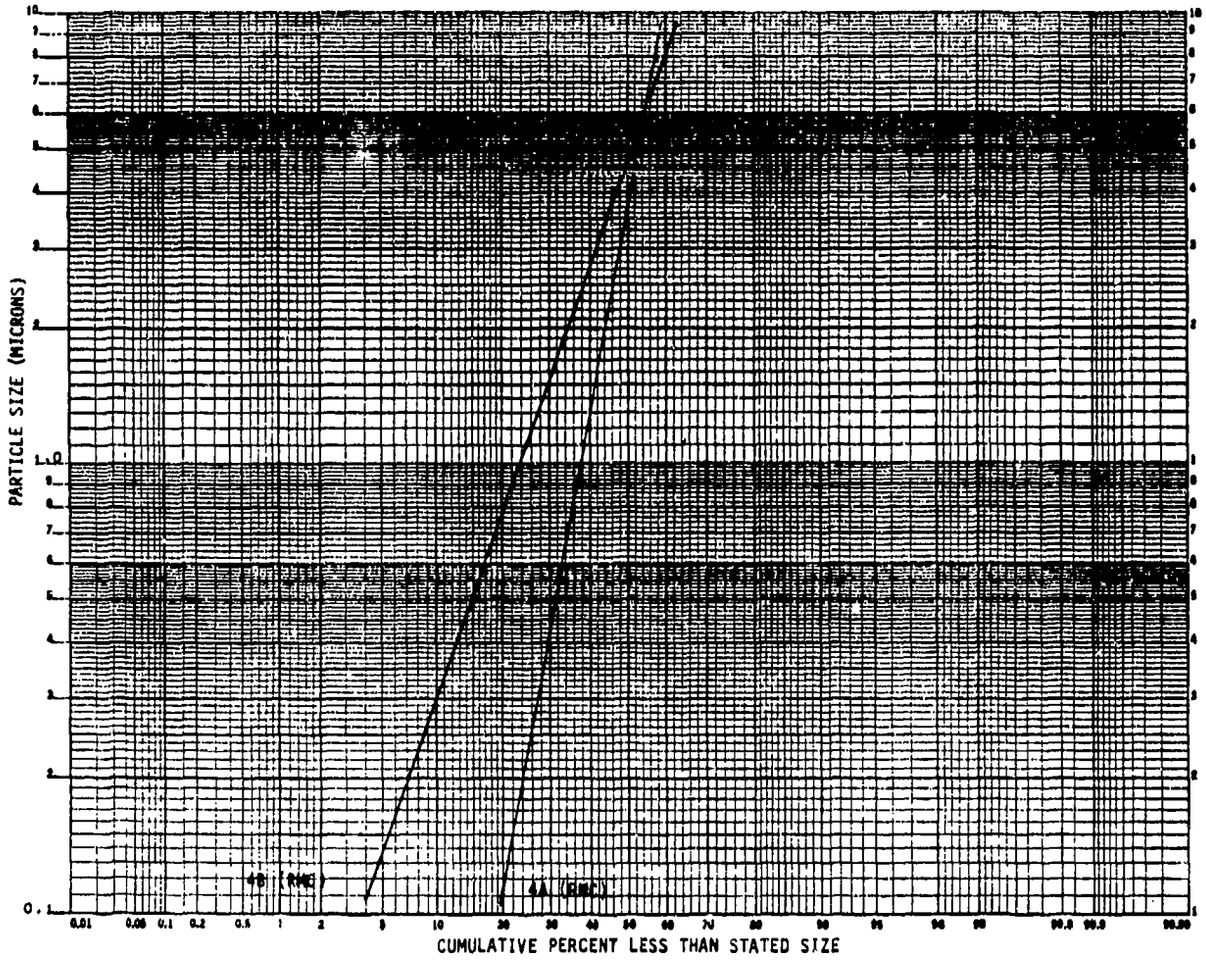

TABLE A-4

RMC ANALYSIS, ROUND 5 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	SPLIT SAMPLE RESULTS (mg)	SAMPLE MEAN (mg)	TOTAL MASS ON FILTER (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	6.55/14.2	10.38	41.5	18.5	81.5
3.3-7.0	2.58/2.32	2.45	9.80	4.36	77.2
2.0-3.3	1.38/1.03	1.20	4.82	2.14	75.0
1.1-2.0	1.65/1.54	1.60	6.38	2.84	72.2
0-1.1	81.2	81.2	162.4	72.2	0

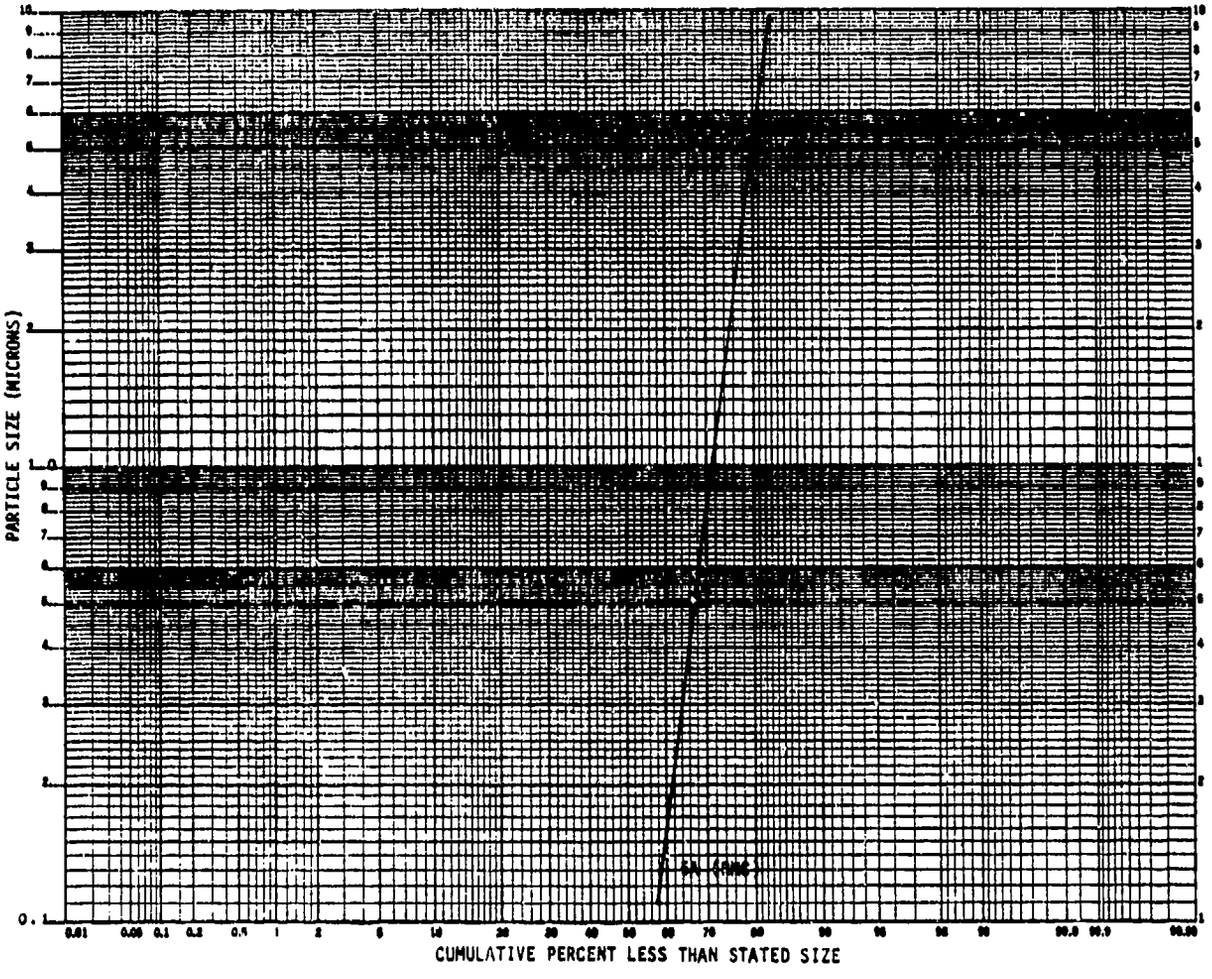

TABLE A-5

RMC ANALYSIS, ROUND 6 PARTICLE SIZE DATA

SAMPLER A

PARTICLE DIAMETER (microns)	SPLIT SAMPLE RESULTS (mg)	SAMPLE MEAN (mg)	TOTAL MASS ON FILTER (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	3.83/5.50	4.66	18.66	30.1	69.9
3.3-7.0	1.39/1.60	1.50	5.98	9.64	60.2
2.0-3.3	0.736/0.880	0.808	3.23	5.21	55.0
1.1-2.0	1.04/1.02	1.03	4.12	6.64	48.4
0-1.1	15.0	15.0	30.0	48.4	0
SAMPLER B					
>7.0	3.11/2.62	2.86	11.5	17.3	82.7
3.3-7.0	1.33/1.39	1.36	5.32	7.99	74.7
2.0-3.3	0.860/0.797	0.828	3.31	4.98	69.7
1.1-2.0	1.77/1.44	1.60	6.42	9.6	60.1
0-1.1	20.0	20.0	40.0	60.1	0

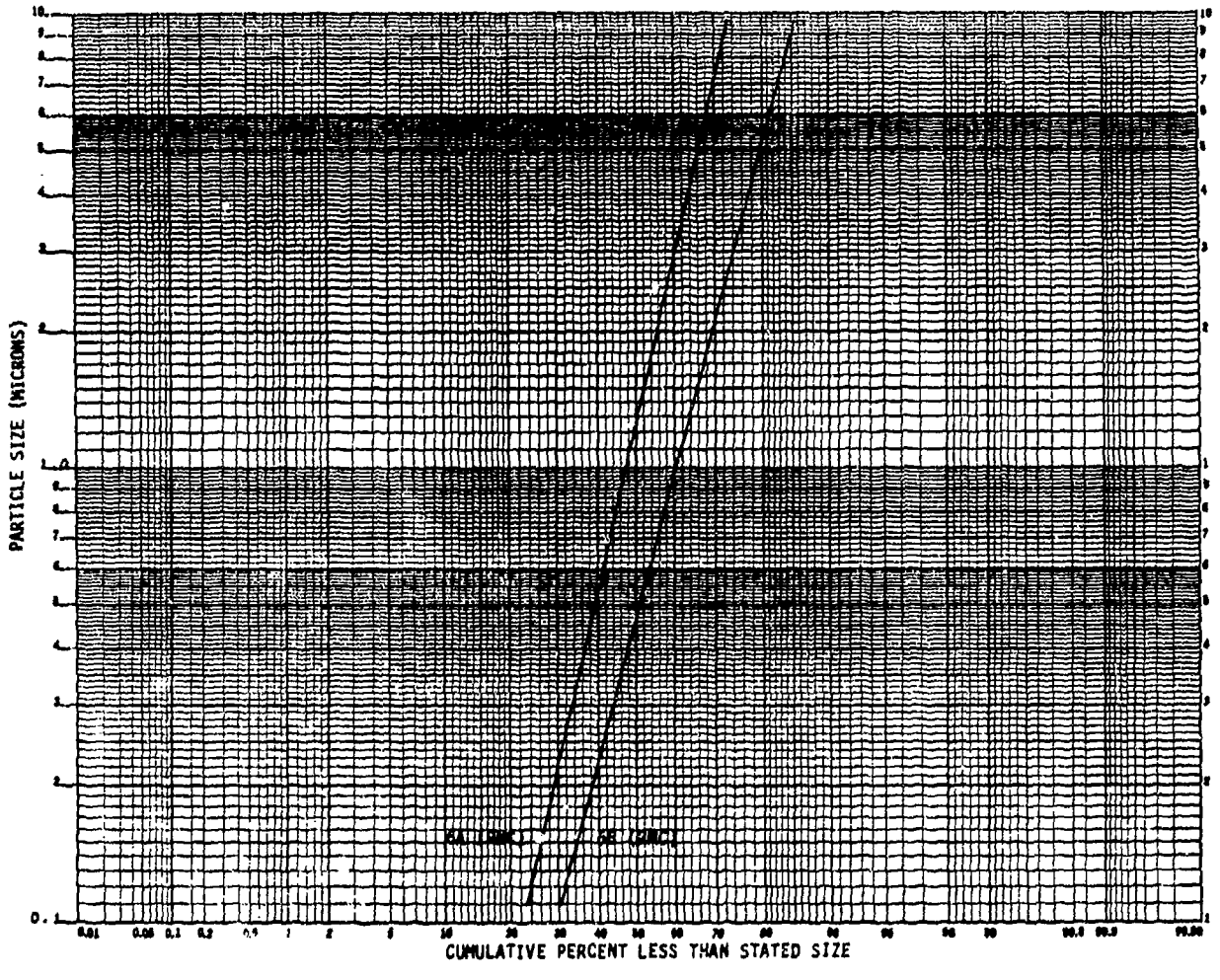

TABLE A-6

RMC ANALYSIS, ROUND 7 PARTICLE SIZE DATA

SAMPLER B

PARTICLE DIAMETER (microns)	SPLIT SAMPLE RESULTS (mg)	SAMPLE MEAN (mg)	TOTAL MASS ON FILTER (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	16.4/46.7	31.6	126.2	35.7	64.4
3.3-7.0	7.46/8.14	7.80	31.2	8.82	55.6
2.0-3.3	3.61/5.68	4.64	18.6	5.26	50.3
1.1-2.0	6.03/15.5	9.56	43.1	12.2	38.1
0-1.1	67.3	67.3	134.6	38.1	0

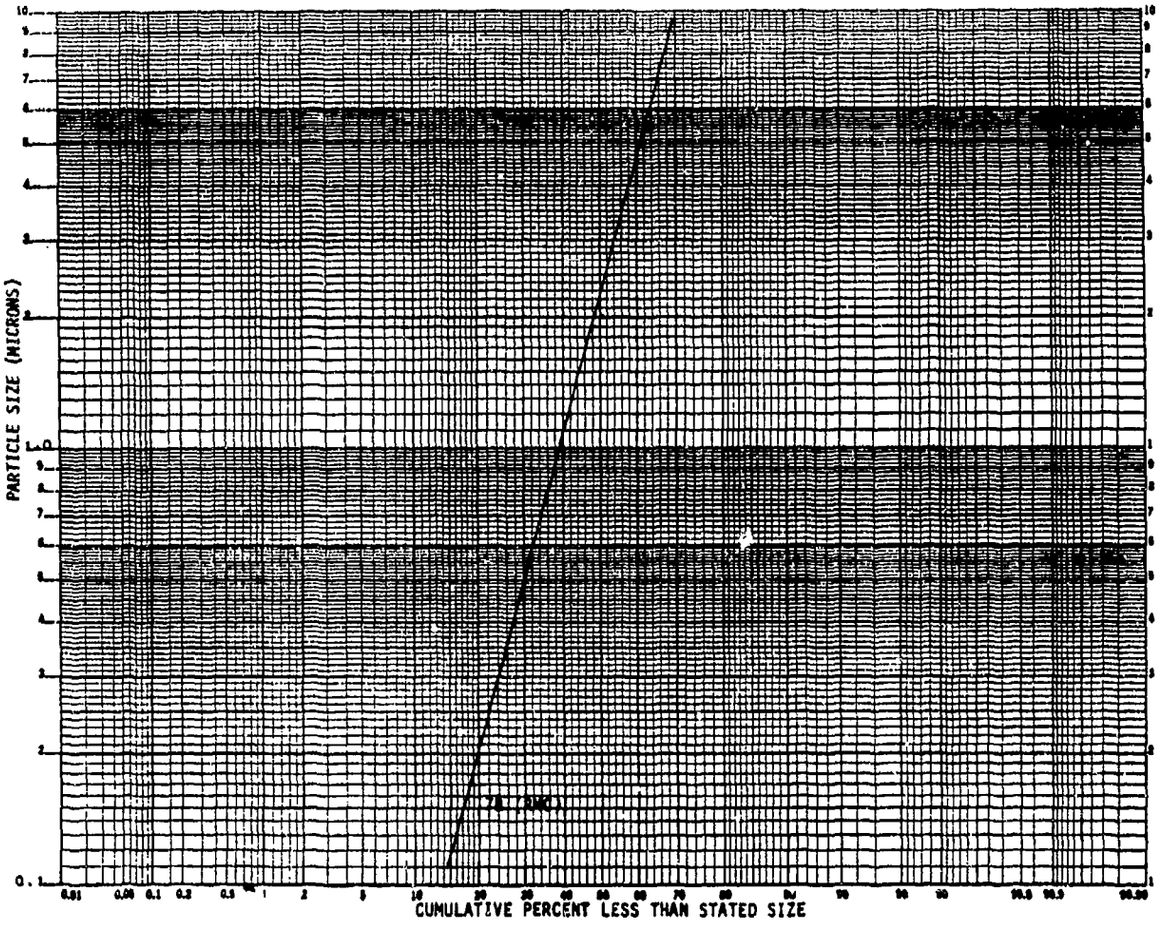

TABLE A-7

RMC ANALYSIS, ROUND 8 PARTICLE SIZE DATA

SAMPLER B

PARTICLE DIAMETER (microns)	SPLIT SAMPLE RESULTS (mg)	SAMPLE MEAN (mg)	TOTAL MASS ON FILTER (mg)	PERCENT IN PARTICLE SIZE RANGE	CUMULATIVE PERCENT LESS THAN STATED SIZE
>7.0	6.23/7.17	6.7	26.8	9.86	90.2
3.3-7.0	3.12/2.01	2.56	10.3	3.79	86.4
2.0-3.3	1.77/1.42	1.60	6.38	2.35	84.0
1.1-2.0	2.2/1.9	2.05	8.20	3.02	81.0
0-1.1	110	110	220	81.0	0

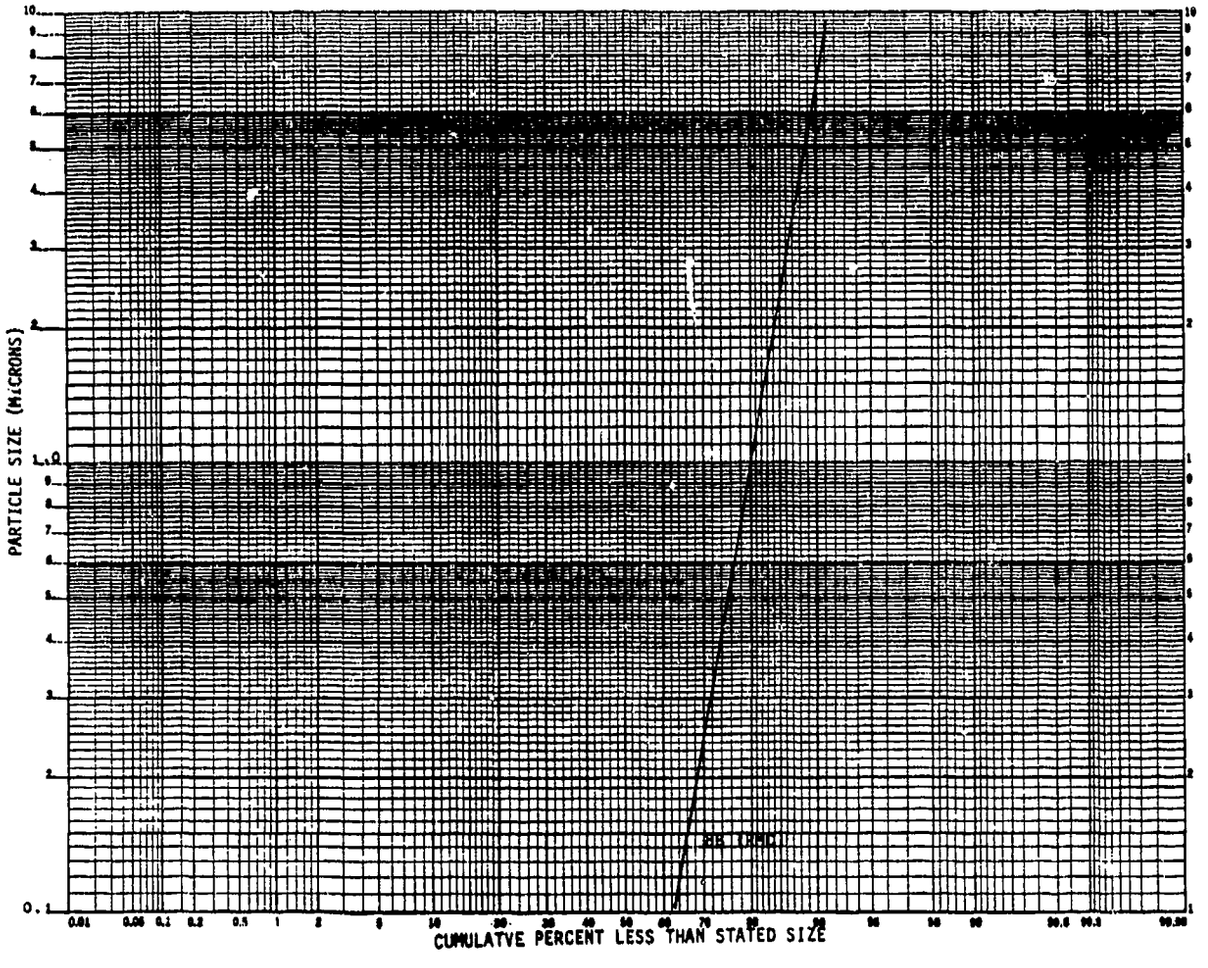

TABLE A-8 SUMMARY OF RMC PARTICLE SIZE IMPACTOR RESULTS

PERCENT IN APPLICABLE SIZE RANGE

SAMPLE NUMBER	>7.0 microns	3.3 - 7.0 microns	2.0 - 3.3 microns	1.1 - 2.0 microns	<1.1 microns	MMAD[1] microns	σg[2] microns
3-A	41.9	7.74	4.35	8.42	37.5	3.2	25
4-A	43.9	5.73	8.59	3.20	38.6	3.7	62
4-B	41.1	16.9	6.97	9.73	25.2	4.7	8.5
5-A	18.5	4.36	2.14	2.84	72.2	0.038	420
6-A	30.1	9.64	5.21	6.64	48.4	1.3	27
6-B	17.3	7.99	4.98	9.60	60.1	0.47	17
7-B	35.7	8.82	5.26	12.2	38.1	2.3	17
8-B	9.86	3.79	2.35	3.-2	81.0	0.025	80
Mean	29.8	8.12	4.98	6.96	50.1	1.1	34

NOTE: (1) *Mass mean aerodynamic diameter*

(2) *Standard geometric deviation*

(3) *Values of MMAD and σg for the mean are derived from the resultant curve, not as the mean of other MMAD σg data.*

ACKNOWLEDGEMENTS

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